

# ENCYCLOPEDIA OF POLLUTION

ALEXANDER E. GATES, PH.D., AND ROBERT P. BLAUVELT



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# INTRODUCTION

The idea for this encyclopedia began with an invitation made to an environmental professional to give a short talk on careers in the environmental industry to an introductory college class at Rutgers University. Robert Blauvelt had the class on the edge of its seat with his stories about dangerous industrial waste affecting residential water supplies, in many cases with criminal intent. The students were so interested that they asked him to return. Considering what a crucial role the environment plays in modern society, and indeed in our very survival as a race, it is important that there be a resource for these students and all of the other concerned people in the world.

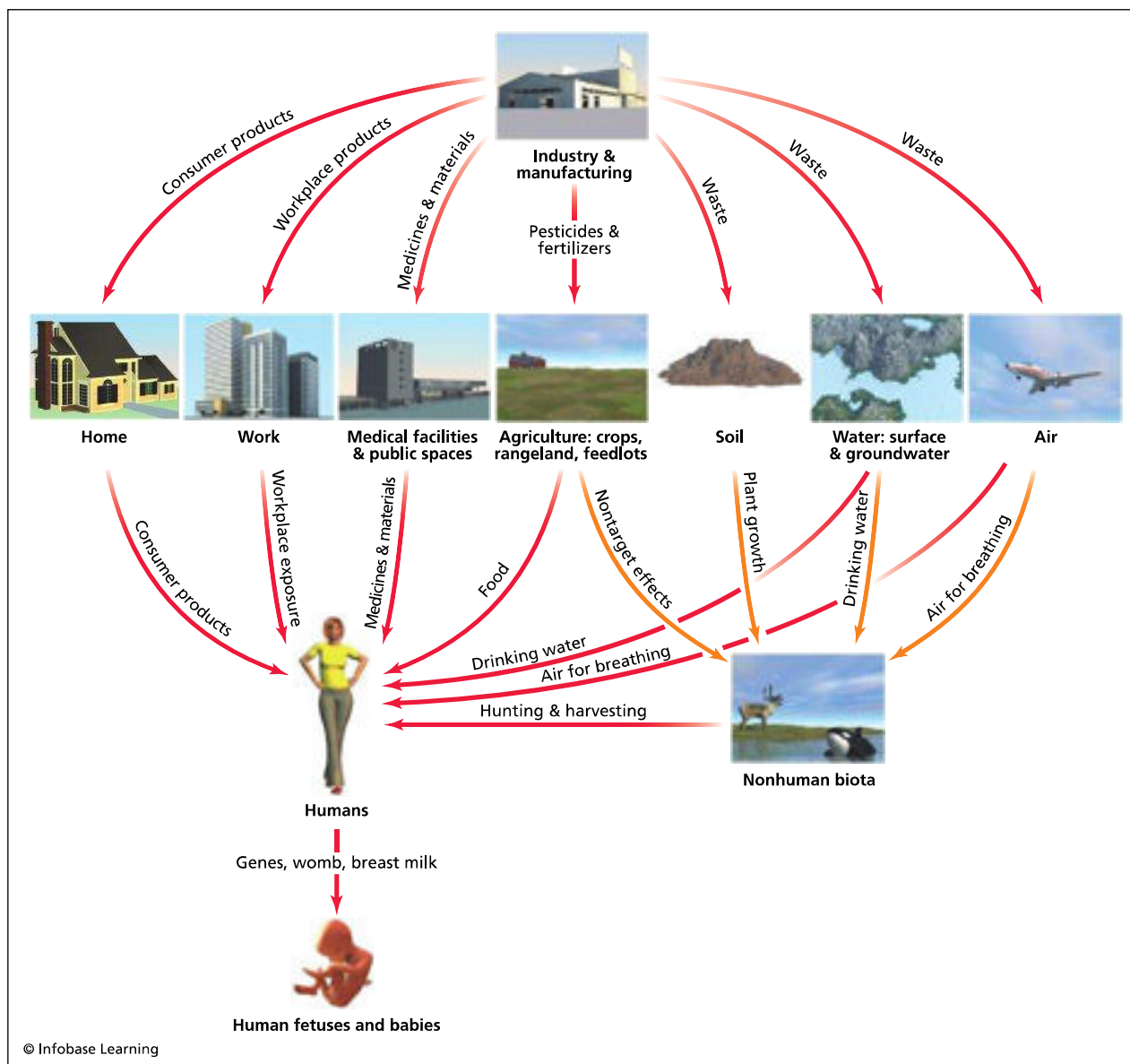
*Encyclopedia of Pollution* is a two-volume set designed to address all aspects of pollution and the entire environmental profession. It is a sourcebook for learning about many different types of pollutants, including properties, production, uses, environmental release and fate, adverse health response to exposure, and environmental regulations on human exposure using the most current scientific data. It provides the scientific background on the water, soil, and air of environments where the pollutants are released. Such environments include terrestrial areas such as streams, wetlands, deserts, glaciers and glaciated areas, and karst terrains, among others, and the soils and water-bearing bodies within these areas. Marine areas include beaches, deltas, and deep marine settings. The processes of the atmosphere, including fronts, hurricanes, and tornadoes, are also addressed as background settings. Pollution regulation and the function of federal regulatory agencies as well as environmental advocacy groups are also described. Finally, the technology and methods to reduce pollution and to remediate existing pollution problems are reported.

These background areas certainly serve as standalone resources for anyone who wishes to investigate any of these areas. This is especially true for details about individual pollutants that are not available elsewhere in a single resource that is readily acces-

sible to a layperson. The background, however, also serves to support the numerous case studies and essays in this compilation. Numerous examples of pollution of all three media—air, soil, and water—are included. These case studies are of the most infamous of pollution events, such as the *Deepwater Horizon* oil spill, the *Exxon Valdez* oil spill, the Gulf Storm oil well fires, the Chernobyl disaster, Hurricane Katrina, the World Trade Center disaster, and Love Canal, New York, among many others, but also include many examples of pollution that might be more obscure but that had great impact on legislation or that were used in popular media, such as the films *Erin Brockovich* and *A Civil Action*, among others. With this encyclopedia, the disaster can be read about, and all of the background—the pollutants, the environmental setting, the applicable legislation, and the remedial technologies—within the case study are readily available for elucidation. This design is intended to give the reader the maximal understanding and appreciation of the pollution event. There are also several biographies of some of the leaders and pioneers of pollution study and environmental activism.

This encyclopedia is arranged in alphabetical order for ease of retrieval if the name of the entry is known. A cross-referencing system is also included on pages xi–xiii for readers who wish to research a specific topic. Entries are categorized into air pollution, water pollution, soil pollution, organic pollutants, inorganic pollutants, pesticides, biological, and biographies. There are summary entries for air pollution, water pollution, soil pollution, organic pollutants, inorganic pollutants, and pesticides that provide an overview of the issues and challenges within each category. These are intended to be a starting point and context for the specific case studies in the group. There are many other ways the entries could be cross-referenced, and there are overview entries on these as well. For example, agriculture and pollution, mining and pollution, and oil spills/offshore oil production could be additional





**A flowchart showing how synthetic chemicals are generated by industry and passed through a number of paths to ultimately affect humans. (Nonhuman biota is also affected by these chemicals.) Although these chemicals typically reach humans and biota in very small amounts, the cumulative effect of this exposure on health is unknown.**

headings under which the entries are subdivided. Rather than generate numerous lists of the same group of entries, only one group of lists is presented.

The final features of this encyclopedia to promote understanding and full appreciation of the issues are several useful appendixes. These include a very detailed glossary to explain unfamiliar words and a list of standard abbreviations for the environmental profession. There are several standard indexes for air and water quality and current rankings of pollutants

and the annual amount released to the environment. There is a time line to put events into historical perspective and these are rankings of major oil spills by volume released, also to provide perspective. Finally, there are tables for Superfund sites and the chemicals present. Superfund sites are the most profoundly polluted places in the nation, requiring direct government intervention to protect environmental and public health. Most of the land-based case studies are or were Superfund sites.

# CROSS-REFERENCED LISTS OF ENTRIES

## Air Pollution

air pollutants and regulation  
air pollution  
Bhopal air pollution disaster  
Chemical Control Corporation  
Chernobyl nuclear disaster  
Doe Run smelter  
Donora Killer Fog  
Environmental Protection  
    Agency (EPA), U.S.  
environmental regulation  
    overview  
dust bowl  
front  
global warming  
Greenpeace  
indoor air pollution  
impacts, extraterrestrial  
London “Killer Fog”  
Los Angeles air quality  
    legislation  
Louisiana-Pacific Corporation  
Marine Shale Processors  
Meuse Valley disaster  
military facilities and the  
    environment  
New York City, air quality of  
Norilsk mine and smelter  
Omaha Lead site  
opacity  
ozone and chlorofluorocarbons  
particulate  
particulate air control devices  
Pennsylvania coal mine fires  
point source and nonpoint source  
    pollution  
Poza Rica disaster  
primary air pollutants  
radiation  
Seveso dioxin release

Sierra Club  
Sudbury mining and air pollution  
sulfur oxide control technologies  
temperature inversion  
Three Mile Island  
tobacco smoke  
urban air pollution  
volcanoes  
Vermiculite Mountain  
war and pollution  
waste  
World Trade Center disaster

## Water Pollution

acid mine drainage (AMD)  
*Aegean Sea* oil spill  
agriculture and pollution  
*Amoco Cadiz* oil spill  
Anniston Army Depot  
antifouling paint  
aquifer  
*Argo Merchant* oil spill  
*Atlantic Empress* oil spill  
Bangladesh, arsenic in soil and  
    groundwater  
beaches  
Beaufort Dyke  
Bell Lumber and Pole Company  
Boston Molasses Disaster  
*Braer* oil spill  
*Burmah Agate* oil spill  
*Castillo de Bellver* oil spill  
continental shelf  
Craney Island  
Cuyahoga River pollution  
dead zone  
*Deepwater Horizon* oil spill  
delta  
Dover Air Force Base  
earthquakes

Edwards Aquifer  
Ekofisk oil field  
Endicott solvent contamination  
Environmental Protection  
    Agency (EPA), U.S.  
environmental regulation  
    overview  
*Erika* oil spill  
ex situ remediation of  
    contaminated groundwater  
*Exxon Valdez* oil spill  
Fairchild Semiconductor  
Feed Materials Production Center  
Floridan Aquifer  
Greenpeace  
groundwater  
Gulf War oil spills  
Haiti deforestation  
Hanford Reservation  
*Hawaiian Patriot* oil spill  
Hill Air Force Base  
Hudson River PCB pollution  
Hurricane Katrina  
hurricanes and pollution  
impacts, extraterrestrial  
influent/effluent streams  
in situ groundwater remediation  
Ixtoc I oil spill  
karst  
Kingston coal ash release  
Kirkwood-Cohansey Aquifer  
leachate  
Love Canal  
marine litter  
McKin Disposal Company  
Milan Army Ammunition Plant  
military facilities and the  
    environment  
mining and pollution  
Nevada Test Site

Norilsk mine and smelter  
 Nowruz Oil Field  
 ocean dumping  
 offshore oil production  
 Ogallala Aquifer  
 oil spills  
 Pacific Gas & Electric Company  
 Petrobras oil platform failure  
*Piper Alpha* oil spill  
 plastic trash in the oceans  
 point source and nonpoint source  
   pollution  
 Pollution Abatement Services  
*Prestige* oil spill  
 Price's Pit  
 radiation  
 Safe Drinking Water Act  
 saltwater incursion  
 Santa Barbara oil spill  
 Savannah River Site  
*Sea Empress* oil spill  
 sewage treatment plants  
 Sierra Club  
 Southern Crop Services  
 streams  
 Stringfellow acid pits  
 Sudbury mining and air pollution  
*Tasman Spirit* oil spill  
 tides  
*Torrey Canyon* oil spill  
 underground storage tank  
 United Chrome Products  
*Urquiola* oil spill  
 Valley of the Drums  
 Waikale Naval Magazine  
 war and pollution  
 waste  
 Waste Isolation Pilot Plant  
 water pollution  
 waves  
 wells  
 wetlands  
 Woburn wells G and H  
 Yucca Mountain Waste  
   Repository

### Soil Pollution

agriculture and pollution  
 Anniston Army Depot  
 Bangladesh, arsenic in soil and  
   groundwater  
 Bell Lumber and Pole Company  
 Blake & Johnson Company  
 brownfields  
 Bunker Hill Complex

coastal plane deposits  
 Craney Island  
 desertification  
 deserts  
 earthquakes  
 Ensign Bickford  
 Environmental Protection  
   Agency (EPA), U.S.  
 environmental regulation  
   overview  
 eutrophication  
 Feed Materials Production  
   Center  
 Formerly Utilized Sites Remedial  
   Action Program (FUSRAP)  
 glacial deposits  
 glaciation  
 Greenpeace  
 Hanford Reservation  
 Hill Air Force Base  
 I-10 Truck Stop, Arizona  
 impacts, extraterrestrial  
 karst  
 Kerr McGee Rare Earths Facility  
 Kingston coal ash release  
 landfill  
 Launch Complex 34  
 Magic Marker Site  
 Mason City Coal Gasification  
   Plant  
 Milan Army Ammunition Plant  
 military facilities and the  
   environment  
 mining and pollution  
 National Zinc  
 Nevada Test Site  
 Omaha Lead site  
 Parsons Chemical  
 point source and nonpoint source  
   pollution  
 Pollution Abatement Services  
 Price's Pit  
 radiation  
 Reactive Metals Extrusion Plant  
 Rocky Mountain Arsenal  
 Savannah River Site  
 Sierra Club  
 soil  
 soil pollution  
 Southern Crop Services  
 Sudbury mining and air pollution  
 Superfund sites  
 Times Beach Superfund site  
 Tittabawassee River  
   contamination

underground storage tank  
 United Chrome Products  
 Usinsk oil spill  
 Waikale Naval Magazine  
 war and pollution  
 waste  
 Waste Isolation Pilot Plant  
 Yucca Mountain Waste  
   Repository

### Organic Pollutants

benzene  
 benzenide  
 carbon tetrachloride  
 chlorinated solvents  
 chlorobenzene  
 chloroform  
 coal tar creosote  
 creosote  
 DCB  
 DCE  
 3,3' dichlorobenzidine  
 dioxin  
 EDB  
 Environmental Protection  
   Agency (EPA), U.S.  
 environmental regulation  
   overview  
 ethylbenzene  
 formaldehyde  
 furan  
 Greenpeace  
 HCB  
 impacts, extraterrestrial  
 MBK  
 MEK  
 melamine  
 methylene chloride  
 military facilities and the  
   environment  
 MTBE  
 naphthalene  
 organic pollutants  
 PAH  
 PCBs  
 PCE  
 perchlorate  
 phthalate  
 point source and nonpoint source  
   pollution  
 radiation  
 Sierra Club  
 styrene  
 TCA  
 TCB

TCE  
toluene  
vinyl chloride  
volatile organic compound  
waste  
xylene

### Inorganic Pollutants

antimony  
arsenic  
asbestos  
barium  
beryllium  
cadmium  
carbon dioxide  
carbon monoxide  
chromium  
cobalt  
cyanide  
Environmental Protection  
Agency (EPA), U.S.  
environmental regulation  
overview  
Greenpeace  
impacts, extraterrestrial  
inorganic pollutants  
lead  
mercury  
military facilities and the  
environment  
nickel  
NO<sub>x</sub>  
ozone  
phosphorus  
point source and nonpoint source  
pollution  
radiation  
radium

radon  
selenium  
Sierra Club  
sulfur dioxide  
waste  
zinc

### Pesticides

aldrin/dieldrin  
atrazine  
carbofuran  
chlordane  
DBCP  
DDT  
diazinon  
disulfoton  
endosulfan  
endrin  
Environmental Protection  
Agency (EPA), U.S.  
environmental regulation  
overview  
Greenpeace  
impacts, extraterrestrial  
HCB  
HCH  
heptachlor  
imidacloprid  
methoxychlor  
methyl parathion  
military facilities and the  
environment  
PCP  
pesticides  
point source and nonpoint source  
pollution  
radiation  
Sierra Club

toxaphene  
waste

### Biological Applications

bioaccumulation and  
biomagnification  
bioremediation  
*Cryptosporidium*  
*E. coli*  
Environmental Protection  
Agency (EPA), U.S.  
environmental regulation  
overview  
eutrophication  
*Giardia*  
Greenpeace  
impacts, extraterrestrial  
military facilities and the  
environment  
mold  
phytotoxicity  
point source and nonpoint source  
pollution  
radiation  
Sierra Club  
waste

### Biographies of Environmentalists

Carson, Rachel  
Crutzen, Paul Josef  
Gore, Al  
Molina, Mario J.  
Muir, John  
Patterson, Clair Cameron “Pat”  
Revelle, Roger Randall  
Dougan  
Stumm, Werner



# ENCYCLOPEDIA OF POLLUTION



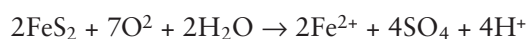


# A

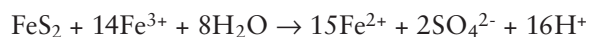
**acid mine drainage (AMD)** Minerals that contain iron, lead, copper, or other metals form the industrial base for most of the world's economies. The extraction, processing, and refining of these minerals, if not done properly, can have adverse environmental consequences. One of the problems that can be caused by poorly implemented mining procedures occurs if water interacts with the sulfur compounds that are often present in the mined ores or waste rock and forms acid mine drainage, a low pH (acidic) solution that can enter nearby surface water bodies and severely damage the ecosystem.

Many mineral deposits contain sulfides, or minerals that include sulfur as the anion (negative atom) in the compound. These sulfides can be economically valuable if the metal in the ore is sought after for use in an industrial process or as part of a finished commodity. Sulfides with zinc, copper, and nickel, among other metals or elements, have retained their commercial value, and sulfides with lead and iron were in demand in the past. In some cases, sulfur by itself is a highly valuable material, which is used in sulfuric acid, matches, explosives, or the production of other chemicals. In many cases, sulfides are unwanted components of an ore deposit, occurring as gangue, worthless materials that must be removed before ore extraction or processing can begin, or as accessory minerals, those present in such a minor amount that they are not an important constituent of the ore. As sulfide minerals are not the primary target of mining, they are left in the waste rock if present at concentrations too low to recover for profit. The sulfur undergoes a series of oxidation reactions in the environment to produce sulfurous and sulfuric acid, which concentrates in

surface water runoff if rain comes into contact with the waste rock. The following equations show how pyrite (iron sulfide), the most common sulfide, reacts with water to form acid:



Pyrite reacts with water and oxygen to form ferrous iron and sulfate (sulfuric acid)



Pyrite, ferric iron, and water react to form ferrous iron and sulfate (sulfuric acid)

Sulfate is a negatively charged compound in which a central sulfur atom is surrounded by four oxygen atoms ( $\text{SO}_4^{2-}$ ). Sulfate ions usually are joined with metals such as barium (barite) or calcium (gypsum) and, if present in sufficient quantities, can be economically valuable. Sulfate mineral deposits also may produce acid mine drainage, but it is typically not as severe as that caused by sulfide-bearing rocks. The acidic runoff from waste rock piles that contain sulfide and sometimes sulfate can do significant damage to the environment both by killing plants and animals and by lowering pH and allowing heavy metals to dissolve into the local water. It is for this reason that acid mine drainage is a serious problem in many areas.

## SOURCE AND MECHANICS OF ACIDITY

Sulfide minerals are usually present in rocks and minerals. They are especially common in hydrothermal deposits, where sulfur and some types of metals

are dissolved in superheated water given off by cooling magma. The most common sulfide, pyrite, also known as fool's gold, can occur in most crystalline rock, but it also can be produced by bacterial action in swamps and other depositional environments. It is for this reason that pyrite most often occurs in shale and coal. In shale, the presence of pyrite results in acidic conditions degrading the quality of the water. If sulfide from pyrite is dissolved in groundwater, it can damage the plumbing in a house that uses untreated well water. Pyrite in coal causes a much more serious problem because it is the main contributor to acid mine drainage.

Weathering of rocks over tens of thousands to millions of years gradually removes the sulfur and associated heavy metals and distributes them into the natural environment in such low concentrations that there is little risk to human health or the environment. Most mined material, however, is not composed of the typical stable, weathered minerals on the surface of the Earth; rather, it is highly reactive material rich in elements that can cause adverse ecological impacts. This occurs because during mining, rock with fresh, unweathered surfaces is raised up to ground level and immediately exposed to wind, rain, and varying temperatures, where the sulfur can be chemically liberated and enter the environment much more quickly and at higher concentrations. Weathering rapidly strips out the sulfur to create acid waters, which in turn dissolve the other unstable minerals, releasing the cations (positively charged ions) into the water. These cations are commonly heavy metals such as lead, nickel, mercury, and arsenic that degrade water quality and damage the environment.

An exacerbating factor in this situation is that the rock is broken into small pieces during the mining process. Weathering and the accompanying chemical reactions take place on the surface of rocks. Smooth natural exposures of bedrock at the surface present minimal surface area upon which chemical weathering can take place. Waste rocks from mines have rough textures, which increase surface area. In addition, surface area increases exponentially as grain size decreases as the coal or other types of sulfur-bearing ore are made smaller to facilitate its handling and shipment. This deadly combination of increased surface area and increased reactivity results in waters that have been changed to the acidic component of the waste rock.

Acidic waters are very damaging to aquatic life. Most freshwater lakes, streams, and ponds have a natural pH in the range of 5.6–8 depending on the rock and soil in which the water resides. Acid water has many harmful ecological effects if the pH of

an aquatic system is below 6 and even more if it is below 5. If the pH is between 5.5 and 5, snails and clams are absent, and populations of fish such as smallmouth bass disappear. Bottom-dwelling bacteria (decomposers) die, leaving leaf litter and detritus to accumulate. This locks up essential nutrients and reduces the availability of carbon, nitrogen, and phosphorus for use by other organisms. Mats of fungi start to replace the bacteria on the substrate. Normal plankton disappear, and undesirable species of plankton and mosses may begin to invade the ecosystem. Metals such as aluminum and lead, which are toxic to aquatic life but normally trapped in sediments, are released into the acid water. If the pH drops below 5, fish populations begin to disappear completely. The bottom becomes covered with undecayed material, and mosses spread and grow to cover near-shore areas. Mayflies and many other insects are unable to survive, and most fish eggs will not hatch. If the pH drops below 4.5, the water will become devoid of fish, most frogs, and insects. If the pH is between 3 and 4, fish are unlikely to stay alive for more than a few hours, but some specialized plants and invertebrates can still survive.

### AREAS OF ACID MINE DRAINAGE

By far the largest area in North America affected by acid mine drainage is the eastern, or Appalachian, coal region of the United States. This area encompasses parts of New York, Pennsylvania, Maryland, West Virginia, Virginia, Tennessee, Alabama, Kentucky, and Ohio, although several other belts are similarly damaged. Coal is removed primarily from underground workings in this region, but strip mining is practiced locally as well. Strip mining involves the removal of large volumes of soil and soft rock that overlie a coal seam or bed. Large excavators called drag lines equipped with rotating grinders then are used to cut or remove the coal for loading and further processing at a nearby mill. This process breaks the coal up into very small pieces, sometimes creating dust and making it easy for water to leach or wash the sulfur out of the coal. Most coal, especially coal mined in the eastern United States, has a high sulfur content, and it is easily dispersed over the surrounding area through ore transportation or storage and as windblown dust. All these factors contribute to extensive acid mine drainage in the vicinity, with a pH commonly in the 3–4 range and in some cases below 3. The acidic surface waters near the mines certainly also have a detrimental effect on aquatic organisms and plants, but, fortunately, they do not extend very far from the source. Much of the bedrock in these areas is limestone, which naturally

buffers (raises the pH) the acidic waters. In some cases, however, despite the buffering capacity of the underlying bedrock, the amount and character of AMD are so pervasive that it overwhelms this naturally available neutralization mechanism and results in adverse environmental impacts.

Acid mine drainage from crystalline rocks is less common because there are fewer mines, and they are generally smaller, underground operations. There are some large mining operations in Colorado and other areas of the western United States involving crystalline rocks, but they are generally isolated and in areas of such low population density that, in most cases, they are not reported by the media. There are some abandoned mines in crystalline rocks in the East that still produce acidic waters, but they are small and largely unreported, as well. One mine in the Hudson Highlands of New York produces waters with a pH as low as 1.77, but it is small and isolated.

In cases where ore processing or smelting is done on-site or near the mines, AMD is much more of a problem. In this case, discharges from smelting and processing operations, as well as from tailings and slag, combine and severely stress the local ecology. There are two cases, in Palmertown, Pennsylvania, and Duck Town, Tennessee, where acid fallout from smelters laid waste the area around them. The Palmertown plant processed the zinc sulfides from the Sterling Zinc Mines in Ogdensburg, New Jersey. The ore was taken in by train and processed on-site for many years. As a result, there is still a large swath along the Lehigh River that still will not grow any trees or anything else. Duck Town largely processed lead sulfide and has become a classic example of ecosystem destruction from acid fallout.

*See also* ARSENIC; LEAD; MERCURY.

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**acrolein** Normally, a contaminant requires both a widespread distribution in Superfund sites and toxicity to achieve a high ranking on the 2007 CERCLA Priority List of Hazardous Substances. Acrolein has been identified in only 32 of the first 1,684 current or former U.S. Environmental Protection Agency (EPA)-designated Superfund sites on the National Priorities List, and yet it is ranked the number 37 worst pollutant on the 2007 CERCLA list. This ranking places it among dangerous substances, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and some of the most notorious pesticides. Although it is more common than the Superfund data might suggest, the real danger of acrolein is its extreme toxicity to humans. Acrolein is also known as 2-propenal, acraldehyde, allyl aldehyde, or acryl aldehyde, but it is not widely available to the general public, so there are not many commercial products that contain it.

#### PROPERTIES, USES, AND PRODUCTION

Acrolein is an organic compound that occurs naturally in the burning of some substances but is primarily synthesized. Chemically, it is the simplest form of an unsaturated aldehyde. Acrolein occurs as a clear or yellow liquid with a burned, sweet, and pungent odor. Acrolein evaporates quickly under normal conditions but even faster as temperature increases. It can therefore be classified as a volatile organic compound (VOC). Acrolein is primarily an intermediary in the production of other chemicals. It is used in the preparation of polyester resin, polyurethane, propylene glycol, acrylic acid, acrylonitrile, and glycerol. It is in this capacity that it is fairly widespread, as these are high-volume products. Acrolein may be found in some livestock feed. In contrast, it is also a pesticide that is added to irrigation canals and the water supplies of some industrial facilities to control underwater plant, algae, and slime growth. At much higher concentrations, it is used to make chemical weapons.

Reported annual production of isolated acrolein between 1980 and the early 1990s is moderate relative to that of many other industrial chemicals. The United States produced between 29,700 and 38,500

tons (27,000–35,000 metric tons) per year, while Japan produced an average of 22,000 tons (20,000 metric tons) per year. France and Germany together produced 66,000 tons (60,000 metric tons) per year, and Russia averaged 11,550 tons (10,500 metric tons) per year.

### ENVIRONMENTAL RELEASE AND FATE

Acrolein can enter the natural environment as both a point source and a nonpoint source pollutant. As a point source pollutant, it moves into air, water, or soil near production, transportation, and storage facilities in addition to hazardous waste sites as the result of spills and leaks. Small amounts of acrolein can enter the air as a nonpoint source pollutant if certain trees and other plants, including tobacco, are burned and when fuels such as gasoline and oil are burned. Acrolein also occurs in building fires at concentrations that can be deadly for occupants.

Once in the air, surface water, or soil, acrolein degrades quickly. In air, the primary area of release, it is quickly degraded by reaction with photochemically generated hydroxyl radicals (air pollution). In cleaner air, it can last long enough to be removed by precipitation (washout). The average removal half-life of acrolein in the air is estimated to be less than 10 hours. If released to surface water, acrolein evaporates, breaks down through chemical reactions, or is biodegraded by microorganisms. The removal half-life of acrolein applied as a herbicide in irrigation canals ranges from 7.3 to 10.2 hours for complete removal by evaporation. The overall removal half-life of acrolein in surface bodies of water is estimated to be between 30 and 100 hours depending upon the stream or channel. In streams and rivers degradation is quicker, especially in warm climates, whereas in lakes it is slower, especially in cold climates. In sediment/water systems, acrolein undergoes chemical and biological degradation. Experimental removal half-lives of 7.6 hours were determined for aerobic conditions and 10 days for anaerobic conditions. An overall reactivity-based half-life is estimated to be between 100 and 300 hours.

If released to soil, most acrolein evaporates from the surface. That which penetrates the soil can be fixed to clay and organic particles or can leach into the groundwater. The overall removal half-life of acrolein in soil through chemical breakdown is estimated to be between 30 and 100 hours depending upon the conditions. If it leaches through the soil, acrolein is very persistent in groundwater. Removal half-lives have been estimated at 11 days for aerobic degradation and 336–1,344 hours (14–56 days) for anaerobic degradation.

According to the EPA Toxic Release Inventory (TRI), there were 248,239 pounds (112,836 kg) of acrolein released to the environment by industry in 2005. This quantity is classified as a moderate amount.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from both acute and chronic exposure to acrolein. For example, it is extremely toxic to humans through inhalation and dermal exposure. Acute exposure through inhalation at levels as low as 10 parts per million (ppm) may result in death in humans. Other effects on the lungs, such as upper respiratory irritation and congestion, occur at very low concentrations. Acrolein is also a strong skin irritant, causing skin burns in humans in both acute and chronic exposure. It results in irritation and tearing of the eyes as well. Animals that ingested acrolein had stomach irritation, vomiting, stomach ulcers, and bleeding. The major effects from chronic, long-term, inhalation exposure to acrolein in humans primarily consist of general respiratory congestion and eye, nose, and throat irritation.

The Department of Health and Human Services (DHHS), the International Agency for Research on Cancer (IARC), and the EPA cannot determine the potential carcinogenicity of acrolein because the current database of scientific studies is inadequate.

### REGULATIONS ON HUMAN EXPOSURE

Several federal regulatory agencies set limits on human exposure to acrolein largely as the result of its extreme toxicity. The EPA has restricted the use of all pesticides containing acrolein and has classified acrolein as a toxic waste. They have set limits on the amount of acrolein allowed into publicly owned wastewater treatment plants. They further require that releases of 1 pound (0.45 kg) or more must be reported to the National Response Center. The Food and Drug Administration requires that levels of acrolein in modified food starch must not exceed 0.6 percent. The Occupational Safety and Health Administration (OSHA) set a limit of 0.1 ppm acrolein in workroom air during an eight-hour workday over a 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) also limits acrolein in workroom air to 0.1 ppm averaged over a 10-hour shift.

*See also* ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE; VOLATILE ORGANIC COMPOUND.



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**Aegean Sea oil spill Galicia, Spain December 13, 1992** *Water Pollution* The economies of the world's industrialized and developing countries are powered primarily by fossil fuels: coal, natural gas, and oil. A ready supply of these relatively inexpensive sources of energy is needed for electrical generation, internal combustion engines, and basic industrial chemicals (inks, fertilizers, medicines, etc.). Worldwide, 3 billion gallons (13.6 billion L) of oil are consumed every day, with the United States using about 23 percent (700 million gallons [2.65 billion L]). Unfortunately, for a variety of geologic reasons, many fossil fuels, particularly oil, are often inconveniently located in areas remote from industrial centers and end use markets. One of the early problems of the Industrial Revolution, which continues to this day, was how to move the oil from where it is to where it is needed. Transportation of oil from remote regions to areas of need can result in accidents and spills. Compared to the oil released to the oceans from urban runoff, spills related to the operation of military and commercial ships, discharge by industrial activities into the air, and natural processes such as seepage from oil-bearing geologic formations caused by earthquakes or erosion, these spills are minor by volume. Although they account for only 6 percent of the oil released into the ocean, discharges from tanker accidents tend to be more ecologically devastating because they occur suddenly; let loose millions of gallons of oil in a single, often confined

place (harbor, bay, or shoreline); and can destroy sea and shore life and habitat over large distances.

One such incident in which a large amount of oil was spilled involved the tanker *Aegean Sea*. Commissioned in 1973 and operated under Greek registry, the *Aegean Sea* was one of the most modern tankers in the world fleet and, just prior to the accident, passed rigorous safety inspections by both United Kingdom and Spanish maritime authorities.

## THE ACCIDENT AND OIL SPILL

In early December 1992, the Panamax oil transport vessel *Aegean Sea* began its relatively short voyage of approximately 800 miles (1,280 km) from the British Petroleum oil terminal *Sullom Voe* in northeast Scotland to the Repsol oil refinery in La Coruña (A Coruña in Galician), Spain. As the ship neared the Spanish coast, in the area known as Galicia, the weather deteriorated dramatically. Named after an ancient Celtic tribe that inhabited the region, Galicia is on the northwest Iberian Peninsula in Spain, bordering Portugal to the south and the regions of Castile and León to the east. The coastline of this area, extending from the villages of Muros and Noia in the south to La Coruña in the north, has been known since Roman times as the Costa da Morte, or Coast of Death. In fact, the Roman name for the region, Finisterre, or "end of the world," is a tribute and warning to its rugged, untamed character. Directly facing the Atlantic Ocean, this part of the Galician coastline has no sheltering islands or bays. Sailing east from Galicia, the next landfall encountered is the east coast of North America. Galicia is a rocky and treacherous area, where the winds and waves can be ferocious and shipwrecks are common.

On December 13, 1992, as the *Aegean Sea* approached the docks of La Coruña near the Repsol oil refinery, sustained winds were more than 60 miles per hour (100 km/h), and visibility was less than 330 feet (100 m). Tanker captains are under enormous pressure from ship owners and operators to make port on schedule. Deliveries often are timed to coincide with expected shifts in oil prices and to maximize refinery output. Despite the terrible weather and the well-known dangers of the coastline, the captain of the *Aegean Sea* decided to berth the ship. As it approached the coastline, however, the winds proved too strong, and the *Aegean Sea* was blown off course and onto the rocks that line the shoreline near the harbor entrance. Its double hull was breached, and 24 million gallons (109 million L) of lightweight crude oil, or "Brent blend," a mixture of oil from petroleum production facilities in the Ninian and Brent fields on the North





Greek oil tanker *Aegean Sea* aground in December 1992 near the harbor of La Coruña, Spain (© Daniel Beltra/Greenpeace)

Sea, was released onto the Galician coastline. After the grounding, almost all of the oil spilled from the tanker and into the water. High winds and the lightweight character of the oil allowed it to disperse quickly, and it eventually covered 125 miles (200 km) of coastline.

Although weather played a key role in creating the disaster, negligence by the ship's captain also contributed to the tragedy. Despite the poor weather conditions, the captain, in violation of several major maritime regulations, entered the shallow bay and approached the La Coruña docks. After grounding, in rough seas and poor visibility, the crew and captain were lifted off their foundering vessel by military helicopter and refused to provide any technical information about the ship, its cargo, or the condition of the vessel. They simply declined to speak about what had happened, fearing they would be held liable. In response, the Spanish authorities promptly arrested the entire ship's company. As a result, the captain immediately made the needed technical details available.

The oil slick created by the spill stretched more than 35 square miles (50 km<sup>2</sup>) and not only decimated the area's fishing and shellfish industries, which employed 20 percent of the residents, but

also shut down the tourist trade, just before a major pilgrimage and festival honoring a local saint. The Spanish government banned more than 800 fishermen from taking mollusks, barnacles, clams, cockles, and oysters for several years until testing indicated that the oil contamination had subsided to safe levels.

### CLEANUP OF THE SPILL

Spanish authorities tried to control and contain the spill, but the bad weather hampered conventional cleanup efforts using booms and skimmers. Instead, the slick was intentionally ignited in a technique known as in situ burning. Not widely used as an oil spill management technique, primarily because of concerns related to air emissions and the ability to control the fire once it is started, in situ burning can be effective when oil slicks are as thin as only 5/10 or 6/10 of an inch (2 or 3 mm). Once ignited, the oil burns the slick down to a thickness of a few tenths of an inch (1 to 2 mm). Below this thickness, the oil does not provide sufficient heat transfer ability to sustain combustion, and the underlying water dissipates most of the heat. In situ burning is used more frequently in remote arctic regions, where there are

fewer concerns over impacts to local air quality. Upon ignition, the slick became an inferno. Flames shot 164 feet (50 m) high into the air, and oil residues coated the Tower of Hercules, a 1,900-year-old Roman lighthouse that is still in active use some 1.6 miles (2.5 km) outside the city of La Coruña. The flames from the *Aegean Sea* burned much brighter, albeit for a much shorter time, than anything the Romans had envisioned as a beacon for this portion of the coastline.

As the fire raged in the harbor outside La Coruña, smoke and soot began to cover the town. Local authorities gave conflicting information to the citizenry, first assuring them that the foul odors and heavy fumes they smelled were not harmful. Then, to be safe, they suggested that residents should evacuate their harborside neighborhoods and seek shelter farther inland. The ability of local emergency response personnel to communicate effectively with residents was hampered by poorly coordinated informational bulletins and press releases and an unwillingness to involve local stakeholders (fishermen, environmentalists, etc.) in the planning and implementation of cleanup activities. Also playing a role in public skepticism was the memory of the 1976 spill of 100,000 tons (91,000 metric tons) of oil from the tanker *Urquiola*, which also washed up onto the Galician coast near La Coruña. It was more than 20 years before compensation claims for this incident were settled.

### LONG-TERM IMPACT AND LEGAL ACTION

Although the fires burned out after a few days, one year after the spill, the rocks along the La Coruña coastline were still coated with oil from the *Aegean Sea*. Biologists and environmental scientists predicted that ecological impacts, including reduced fishery yields, could linger for up to 10 years. Oil is still found today trapped below the rocky shoreline.

The International Oil Pollution Compensation (IOPC) Fund and the Spanish government established a claims office in La Coruña and began to process almost 1,000 claims by individuals, firms, and cooperatives for damage caused by the spill and subsequent fire. Upward of 320 million euros (\$200 million) was at stake, and most claimants also began legal proceedings. Eventually, the *Aegean Sea* captain, the vessel's owner, and the Spanish government were found jointly liable for the accident. Although claims related to loss of income from tourism, fishing, and fish farming were settled in a timely manner, those associated with shellfish harvesting were not resolved until 2002. As a result of the *Aegean Sea* disaster, the European Union adapted more

stringent procedures for ships entering harbors and approved new measures to protect traditional fishing areas and other ecologically sensitive zones.

See also OIL SPILLS; TORREY CANYON OIL SPILL; URQUIOLA OIL SPILL; WATER POLLUTION.

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**agriculture and pollution** In general, people do not want to consider that the most important activity for humankind's survival could be a grave source of pollution. By disrupting the naturally developed ecosystem of an area through the addition of water, fertilizers, pesticides, and nonnative plants, poorly conceived and implemented agricultural and horticultural practices not only are a major source of environmental damage, but also may be the largest source of pollution on the planet. It is debatable whether pollution from energy exceeds that of agriculture. The burgeoning human population on the planet, now almost 7 billion and growing, is consuming resources at such a breakneck pace that society has resorted to unsustainable practices in agriculture. Humans have even attempted the potentially risky practice of genetically engineering sources of food to increase the yields of such crops as corn and tomatoes. In 2005, a panel of experts convened at the United Nations (UN) Food and Agriculture Organization (FAO) recommended that "... any responsible deployment of Genetically Modified (GM) crops needs to comprise the whole technology development process, from the pre-release risk assessment, to biosafety considerations and post release monitoring." These recommendations are based on fears of

unanticipated side effects, but if serious efforts are not made to curtail population growth, there will be no choice but to continue to utilize genetic engineering to make crops more productive, nutritional, and disease- and pest-resistant.

There are many sources and effects of pollution in agriculture. There are sources, for example, that are specific to crops and those that are specific to livestock. Within each of these subdivisions, there are certain direct effects, such as pesticide and fertilizer use on crops, and indirect effects, such as eutrophication and dead zones from these practices. Some only result from catastrophic events such as flooding and earthquakes, others from long-term practices related to increasing the productivity of the land or a specific harvest. It is these cumulative effects from both sources that make agriculture a potentially serious pollution threat.

### **POLLUTION FROM GROWING CROPS**

Growing crops is, by far, the greatest source of pollution in agriculture. The U.S. Environmental Protection Agency (EPA) has estimated that agriculture-related pollution is the leading source of water

quality impacts to rivers and lakes, the third largest source of impairments to estuaries, and a major contributor to groundwater contamination and wetlands degradation. The environment is polluted primarily from farming practices, the use of pesticides, and the application of fertilizers. There are other sources of pollution, such as energy consumption in farming and in transportation of supplies to the farm and produce out to market. These additional sources of pollution are relatively minor when seen individually and even grouped together are small compared to the others.

There are several types of farming practices that are causing environmental problems now or in the past. They can be significant but typically are only noticed by officials and acted upon when they become extreme. Although there are many minor practices that contribute to pollution, the three major farming practices are deforestation, soil preparation, and use of water for irrigation and crop processing (cleaning, sorting, etc.).

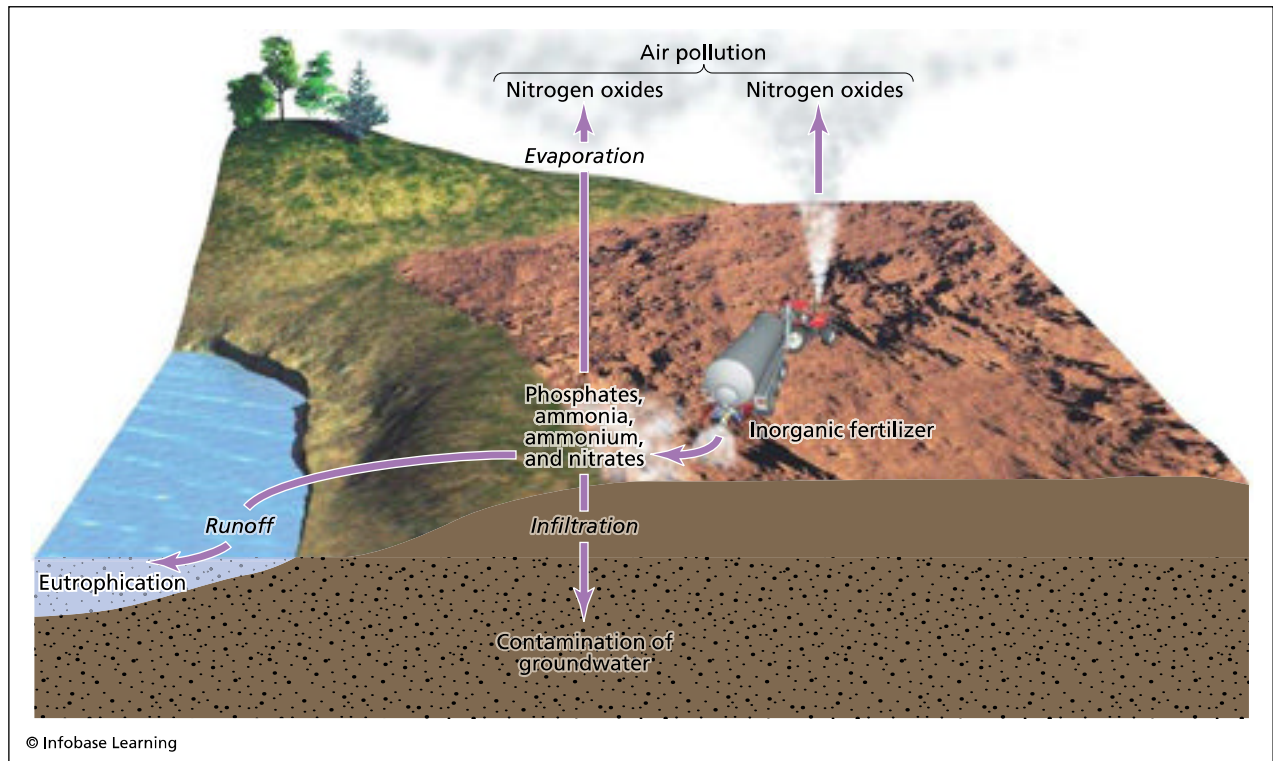
### **Deforestation**

Trees are not helpful in growing most crops because they reduce sunlight and consequently photosyn-



**Crop dusting at Everglades Agricultural Area, a 700,000-acre (283,280-ha) tract of farmland created from the drainage of the northern Everglades, Florida (Florida Images/Alamy)**





**A diagram that shows how farming practices can cause pollution of soil, surface water, groundwater, and air through the use of inorganic fertilizers. The three processes creating pollution in addition to direct application to soil are evaporation to air, infiltration to groundwater, and runoff to surface water.**

thesis, and they commonly emit debris and growth inhibitors to reduce competing vegetation. As a result, trees are customarily removed prior to beginning an agricultural program. This has been the standard practice since farming began. Trees were cut down and the stumps pulled out to prepare fields for planting. Some of the wood may have been used for construction and heat for a home, but much of it was simply burned. In some cases, the area to be cleared was set ablaze and all of the vegetation just burned away. In either case, deforestation is not an environmentally friendly process.

There was always some pollution associated with deforestation. The burning of the wood and other vegetation produces particulate and other chemical pollutants, such as creosote, carbon dioxide, benzene, and polycyclic aromatic hydrocarbons (PAHs) among others. Trees are outstanding at stabilizing soil. When they are removed, there is necessarily some soil erosion that can silt up streams and other surface water bodies. It also increases mass movement of soil (e.g., landslides) that have their own set of related pollution events.

The current problems of concern with deforestation are greenhouse gases and global warming. By virtue of their size and rapid growth, there is a high

ratio of photosynthesis to ground space in a tree. Trees convert more carbon dioxide to oxygen than most other types of vegetation. Stripping large trees in favor of smaller and more widely spaced crop plants generally reduces the amount of photosynthesis, and, in many cases, the reduction is significant. Deforestation is indirectly adding more carbon dioxide to the atmosphere.

There is no place on Earth where this is more of a problem than in the tropical rain forests, particularly in Central and South America. They are continuously being bulldozed over and burned to make room for croplands at a breakneck pace. Roughly half of all tropical rain forests worldwide, or 1.85 million of 3.7 million acres (750,000 of 1.5 million ha), have been destroyed, and, at the current rate of cropland conversion, only 10 percent will remain by 2030. This practice is contributing to the carbon dioxide problem because, unlike at high latitudes, these trees and associated vegetation grow and photosynthesize throughout the year rather than only in growing seasons. It is estimated that the rain forests have historically produced 20 percent of the world's oxygen from photosynthesis. In addition, all of the nutrients for growth are contained in the vegetation, litter, and canopy. The soils beneath are deeply

weathered lateritic types with all of their nutrients long since stripped away by chemical weathering. Tropical soils must be continuously supplemented with fertilizers to support vegetation, and if they are abandoned, many decades to centuries are required to restore them to their original natural and productive state.

### Soil Preparation

Since the beginning of civilization, the practice of soil preparation involved plowing of the soil. This practice is and was done to soften the soil and to turn under and kill the native vegetation. The softened soil allows easier planting of seeds and easier penetration of the roots into the ground. Rapid penetration allows quicker growth of the plants to larger size, as the root size is commonly proportional to the plant size. Plowed soil also allows better use and drainage of water, which infiltrates the soil and is delivered to the root systems more quickly, with less lost to runoff.

But native vegetation serves many functions in protecting the soil. It holds moisture in, thereby preventing the soil from drying out. It also prevents the soil from eroding any further than the practice of deforestation has already caused. The result of ground preparation for the crops is and was wide, open bare soil at the mercy of the elements. Fortunately for us, normally the elements are kind and farmers can plant and harvest their fields without much problem. In some years, however, that is and was not the case.

In the South Central United States, there was a particularly hot and dry weather period beginning in 1926 and continuing to 1934 but not fully recovering to normal conditions until the end of the 1930s. The exposed soil dried out on the fields, and cover vegetation did not even take over during the off-seasons. Even the most fertile soil became a dry powder. When the winds came, they blew much of this powder into great clouds and storms of dust or particulate. It was for this reason that the term *dust bowl* was coined. When a dust storm struck, the particulate was so thick that there was no visibility. People put sheets over their doors and windows, but the dust got into everything and settled onto houses, on the ground, and into streams, up to several feet deep in some cases. It silted up streams and polluted the air. People suffered increased respiratory illness from inhaling the dust.

The dust bowl ended and new farming practices were introduced to curtail such events in the future. The dust bowl is a stark example of how agricultural practices can produce pollution problems. The change in conditions during the dust bowl was so

great that the government and residents alike agreed to change farming practices. The same problem has happened and is happening in many other places around the world, but in most cases it is more subtle and as a result is not acted upon as quickly or effectively as it should be.

### Water Usage

Crops need water in order to grow. Natural precipitation would be the most efficient and best source of this water, but nature is not reliable enough for our needs. Therefore, farmers must water their fields. In the early days, people simply planted near bodies of water, such as rivers, and hoped they would not flood. Otherwise, they would lose an entire year's crop. This was a devastating event. To avoid such catastrophes and because they quickly ran out of space, farmers began planting farther from rivers. As a result, they were forced to devise irrigation systems, which have grown ever more efficient and complicated over the years. If cropland is near a non-estuarine river or other surface water body, typically there will be a combination of surface water and well water used for irrigation. If the land is distant from a surface water source, irrigation is provided purely by well water.

The main pollution problems associated with water usage are desertification and degradation of the water source as a result of drawdown. The best example of desertification resulting from overuse of surface water for irrigation is the Aral Sea in Russia. Enhanced agricultural efforts in the region required excessive irrigation because the area is so dry. As a result, the Aral Sea began to shrink and soon lost one third of its area before agricultural activities subsided in the area. The newly exposed land is primarily a desert.

Overuse of water also can affect river systems. Although much water in a river is also typically used as drinking water, the agricultural component can be very high. Just as with the Colorado River, the primary effect is decrease in discharge caused by the reduced volume. The secondary effect is the degradation of water quality. The lower water level tends to draw more base flow from the water table into the river as it increases its effluence. Polluted groundwater may be drawn from greater distances to the river; runoff, which is of notoriously lower quality, makes up a larger percentage of the river water, and the shallower water in the river allows a higher degree of evaporation, thus increasing salinity. The same effects can occur in lakes and ponds.

The truly worrisome part of overuse of water is the effect on major aquifers. Some aquifers, the High Plains, or Ogallala, Aquifer of the midwest-

ern United States, for example, are primarily used for irrigation. The Ogallala is used 94 percent for irrigation, and the heavy draw from it has dropped the water table 100 feet (30 m) on average and up to 175 feet (54 m) in some areas. It has drastically altered the depth and dynamics of the streams and rivers in the area because base flow is reduced. It also tends to draw more water from areas that are somewhat saline as well as from the surface, and, consequently, the quality of the water has suffered as well. The water in the Ogallala is largely recharged from surface, but there are other aquifers that were formed during the last ice age, 13,000 years ago, and recharge has been very slow ever since. This water is being drained and not replaced. Eventually, these aquifers will no longer be able to irrigate the farmlands and a crisis may ensue.

### AGRICULTURAL CHEMICALS

Agricultural chemicals are those manufactured substances or cultivated organisms that are used to destroy, stupefy, repel, inhibit the feeding of, or prevent pests from attacking plants or other related products. These include agents that destroy a plant or modify its physiology, modify the effect of

another agricultural chemical product, or attract a pest for the purpose of destroying it. Typically, agricultural chemicals include herbicides, insecticides, and fungicides. Fertilizers are not considered agricultural chemical products. Some government regulatory agencies also classify plant growth regulators (hormones) and veterinary medicines as agricultural chemicals that require special registration and application controls.

The use of agricultural chemicals is one of the main reasons that farmers are able to feed more people with crops produced from the same amount of land. For example, China produces enough food for 21 percent of the world population on 9 percent of the world's cultivated land. This is possible only because 75 percent of crop nutrients are now supplied and managed by agricultural chemicals, particularly fertilizers. The use, and often overuse, of agricultural chemicals, however, can have severe ecological and environmental implications.

### Pesticides

Pesticides have been one of the greatest inventions of humankind and yet may cause the most problems as pollutants. Pesticides have eliminated many of the insects and other pests that reduce crop yield.



Erosion along Cane Creek, 1985, caused by an upstream channelization project © Karen Kasmauski/CORBIS





Honey bee (*Apis mellifera*) on white flower (Elemental Imaging, 2008; used under license from Shutterstock, Inc.)

The relationship of American farmers and pesticides has been described as a love affair. They have been used with wanton abandon to increase crop yield, and, as a result, they have turned the Midwest into the breadbasket of the world. They have allowed enough food to be produced to supply the burgeoning human population. They are truly one of the saviors of civilization.

The overuse of pesticides has negative aspects as well. The negative issues with pesticides are now well known as the result of the tireless efforts of environmental activists. Rachel Carson began her crusade against environmental pollutants, particularly against pesticides. Her 1962 book *Silent Spring* identified by name the most dangerous of pesticides, particularly dichlorodiphenyltrichloroethane (DDT). These efforts eventually resulted in the formation of the U.S. Environmental Protection Agency (EPA) and the banning of DDT and many other agricultural pesticides of the time. Other heavily regulated or completely banned pesticides include aldrin/dieldrin, carbofuran, chlordane, 1,2-dibrom, 3-chloropropane (DBCP), diazinon, endosulfan, endrin, hexachlorobenzene (HCB), hexachlorocyclohexane (HCH) or lindane, heptachlor, methyl parathion, pentachlorophenol (PCP), and toxaphene, among others.

The reason that all of these pesticides that took years to develop at great cost were banned was not their effect on pests but their collateral damage to people and the environment. One of the defining events that caused Rachel Carson to become involved in opposing the use of DDT was a bird kill in Massachusetts that resulted from indiscriminant application of DDT. Later, it was found that the Cal-

ifornia condor was becoming extinct because DDT in its body was causing its eggs to have such a thin shell that they broke before hatching. Even though it ultimately survived, through the late 1960s, the California condor was a battle cry for opponents of DDT. It was not only birds that were suffering from pesticides. The frog and amphibian kills from pesticides and destruction of habitat are even more impressive. Estimates are 122 species of amphibians have been lost since 1980 and that 32 percent of the remaining species are on the brink of extinction. In Central America, two thirds of the native frogs are extinct. These numbers are equivalent to the worst extinction events in the history of the planet.

Most people are generally not overly concerned with the losses of wild birds and frogs because they do not affect them directly. Another failing group that may be of a bit more concern are bees. The population of bees in North America has been steadily decreasing since the widespread use of pesticides began in the 1940s. This slow decrease abruptly changed to a precipitous drop in the 2000s. A new syndrome called colony collapse disorder (CCD) began to wipe out whole nests at a time in great numbers. Between 2006 and 2007, it is estimated, one third of the remaining bees died off. The cause of CCD is still under debate, and parasites and viruses have been the leading theorized agents. Pesticides have certainly taken their toll on bees because many of them are at least as toxic to bees as they are to the target insects. The pesticide imidacloprid has emerged as a likely contributor to the problem because it is relatively safe to humans and mammals but very toxic to insects. It is consequently used in higher quantities than perhaps it should be.

The loss of bees will not only decrease our supply of honey. Bees are the main pollinators for most of our fruits and vegetables. There are already problems for cranberries, blueberries, and apples from just the decreasing bee populations. Albert Einstein is credited with having said that if the bees became extinct, humans would follow within four years. Without them, the food supplies would dwindle until we starve to death.

Pesticides also get into the water supply from washing off fields during precipitation into the surface runoff. This runoff enters the surface water system in lakes and rivers that may be used for human consumption. Some pesticides are systemic, meaning they are taken into the plants through the roots and distributed throughout the plant. When the plant is harvested, the pesticide is included and cannot be removed. Pesticides are also blown into the atmosphere, where they can be carried great distances. Pesticide residues have been found in glacial ice in Greenland. All of



this exposure to persistent pesticides increases their level in the human body. In the 1970s, the levels of pesticides in human mother's milk were found to be dangerous. With all of the efforts to reduce ambient pesticides in foods and common items, levels of pesticides in human milk have been reduced to moderate levels. The long-term health effects of exposure to pesticides have yet to be determined.

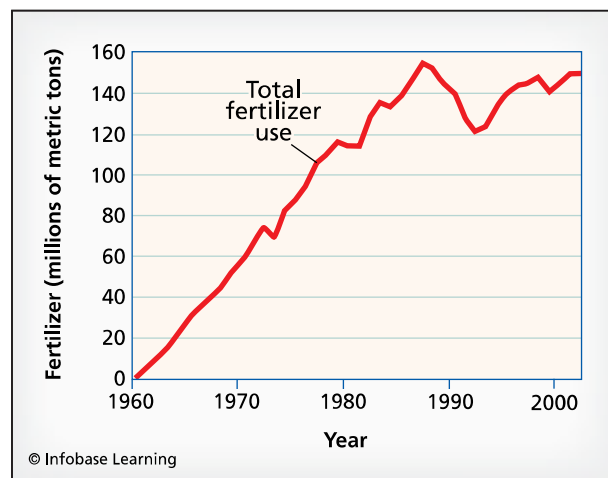
### AGRICULTURAL NUTRIENTS

Fertilizers are nutrients needed to grow plentiful, useful plants. They can be divided into two basic categories: macronutrients (needed by plants in large quantities) and micronutrients (necessary in much smaller amounts). Macronutrients include nitrogen (N), phosphorus (P), and potassium (K), and some agricultural experts add sulfur (S) to the list. Nutrients required in small amounts (sometimes called trace elements or secondary nutrients) include boron (B), copper (Cu), iron (Fe), chlorine (Cl), manganese (Mn), molybdenum (Mo), and zinc (Zn). Fertilizers are the materials developed to deliver these macro- and micronutrients to the soil in a way that they can be utilized by plants. All of these nutrients are present in nature, but not in the quantities sufficient to satisfy the needs of the world's expanding urbanized population. According to 2007 statistics provided by the International Fertilizer Industry Association, the global fertilizer industry produces some 187 million tons (170 million metric tons) of fertilizers annually. There is no substitute for the nutrients absorbed by crops, and fertilizers are essential ingredients in a sustainable food supply.

#### Fertilizers

The other savior of humankind is agricultural fertilizer. In years past, natural fertilizers were used but were limited in their effectiveness. The recent and new chemical fertilizers that have been developed and tested in laboratories are extremely effective for growing crops with the highest yield in the shortest growing season possible. The output of plants allows farmers to produce more food, and, with more food, a larger human population can be maintained. The burgeoning population and enhanced lifestyle are largely the result of effective fertilizers.

The more the population increases, the more the demand there is on farmers to produce food. Consequently, farmers use even more fertilizers, to the point where they are at excess levels in the environment. These excess levels mainly affect surface water. A small part of the applied fertilizers are swept off fields in runoff after a rainstorm. If they migrate into a surface water system, they strongly

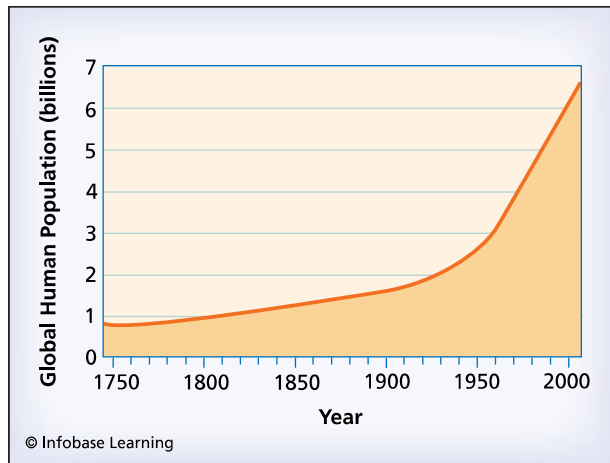


**A graph showing the increased use of fertilizer from 1960 to 2000—the drop in the 1990s reflects the decline and reorganization of the former Soviet Union.**

affect it. Nearly every pond and small lake in the United States is affected by excess nutrients such as the kind introduced by fertilizers. These excess nutrients cause eutrophication of the pond, which is a condition in which an initial algal and plant bloom results in massive oxygen-consuming bacterial growth to consume dead vegetation. The pond becomes hypoxic (oxygen deficient), and much of the native life dies.

Minimal efforts were made to battle eutrophication because ponds and small lakes are not major suppliers of food. In the 1960s, however, a major zone of eutrophication (oxygen deficiency) appeared in the Black Sea of the USSR as the result of runoff from overfertilized cropland. The zone was named a dead zone because virtually all of the fish and invertebrate life either died or quickly fled the area, leaving it devoid of life. Only minor notice was taken of the phenomenon because it was in the USSR and because the Black Sea is small and restricted. These dead zones began appearing in other places as well through the 1980s and 1990s and continuing today. They primarily appear where rivers empty into the seas or oceans in bodies of water with somewhat restricted circulation. The fertilizer is swept into runoff, and the rivers carry it to the sea, where it accumulates. For example, the Mississippi River drains the entire breadbasket of the United States, and, as a result, one of the largest dead zones in the world is in the Gulf of Mexico at the mouth of the Mississippi.

There are now more than 200 dead zones worldwide and most are associated with overuse of agricultural fertilizer. These growing areas are devoid of edible marine life and as such are severely reducing output. The zones appear in the most productive



**A graph showing the growth of human population from 1750 to 2000**

marine areas, such as the Gulf of Mexico, Chesapeake Bay, and coastal Oregon. They are reducing the marine food supply, and if dead zones are left unchecked, they may lead to a global food crisis.

### POLLUTION FROM LIVESTOCK

Aside from the inhumane treatment of livestock in order to meet the demands of burgeoning human population, there are certain sources of pollution to the environment and threats to public health. Many crops are grown for livestock, so pollution generated in the process is at least partly attributable to livestock. Direct pollution from livestock is largely caused by waste except in catastrophic events. With huge numbers of livestock come huge amounts of animal waste to deal with. At times, this waste has contact with the food supply and there are outbreaks of *Escherichia coli* and *Salmonella*, among other bacteria, that can spread across the nation, causing sickness and sometimes death. Considering the vast amount of produce generated, these outbreaks are relatively rare.

The main problem is the disposal of the waste. In smaller operations, runoff from piles of waste flows into streams and rivers, causing eutrophication. In bigger commercial operations, the waste is pumped into large lagoons. There is significant generation of methane during the breakdown of waste. Flatulence from cows also contributes to the methane production from these areas. In the United States, cattle emit about 6 million tons (5.5 million metric tons) of methane per year to the atmosphere, accounting for 20 percent of total methane emissions. Methane is 23 times as strong a greenhouse gas as carbon dioxide.

There also are natural catastrophic events that can be devastating to those operations that are at maximal

capacity for the number of livestock. Catastrophic events have always been very damaging to livestock. Domestic animals lose their native instincts when they are herded and corralled their whole life, especially when many generations pass. In catastrophic events, animals commonly need that instinct to survive. The eruption of the Laki volcano in Iceland in 1783 emitted huge amounts of fluorine gas, which settled on and poisoned fields. The livestock ate the poisoned grass, and hundreds of thousands of them died. The 1920 Gansu earthquake in China is reported to have killed 200,000 livestock. These animal carcasses must be disposed of by burning or burying them in a secure grave as quickly as human bodies are, or they will generate disease and pollute local water supplies. Outbreaks of diseases such as cholera and dysentery can be as devastating as the disaster itself.

One of the most colorful cases of a natural disaster overwhelming livestock operations was Hurricane Floyd in North Carolina. Eastern North Carolina became a center for hog production. This growth was especially quick in the 1990s, when it grew from 2 million hogs in 1990 to 10 million hogs by 1997, making it the second largest hog producer in the United States. The area is low-lying and wet with a large number of streams and rivers. The hog waste was pumped into huge lagoons, 300 feet (92 m) by 150 feet (46 m), and filled 10–15 feet (3–5 m) deep in waste, many of which were in flood plains of rivers. By 1999, there were more than 4,000 waste lagoons in the area. In August 1999, Hurricane Dennis inundated the hog farming area with rain and flooded many streams. Two weeks later, before it could recover, Hurricane Floyd struck the same area. The flooding killed approximately 30,000 hogs, 2 million chickens, and 735,000 turkeys. It also washed out 38 waste lagoons completely and caused another 250 to overflow. It is estimated that 250 million gallons (950 million L) of untreated pig waste was dumped into rivers along with a huge number of carcasses. The smell was absolutely overpowering and prevented people from drinking the water, which was tainted with disease.

See also CARBON DIOXIDE; CARSON, RACHEL; DEAD ZONE; DESERTIFICATION; EUTROPHICATION; GLOBAL WARMING; IMIDACLOPRID; OGALLALA AQUIFER; PAH; PARTICULATE; PESTICIDES.

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**air pollutants and regulation** The basis of air pollution regulation in the United States is the Clean Air Act. Originally passed in 1955 and called the Air Pollution Control Act (APCA), this was the first federal legislative action that addressed air pollution on a nationwide level. The 1955 APCA was directed to alert the nation to the problem of air pollution and allocate funds to study and define the problem. Eight years later, Congress took the next step and passed the Clean Air Act of 1963. This act set the first emission standards, or the amount of pollutants that was allowed to be discharged from a stationary source, such as a smokestack or chimney. Amendments to strengthen the act were passed in 1965, 1966, 1967, and 1969 and fixed limits on pollution from automotive vehicles, instituted compliance deadlines and schedules, expanded state and regional air quality control programs, and funded research on low-emission fuels.

Even with the regulations, improvements in air quality were moving too slowly. In 1970, the Clean Air Act was significantly strengthened through the

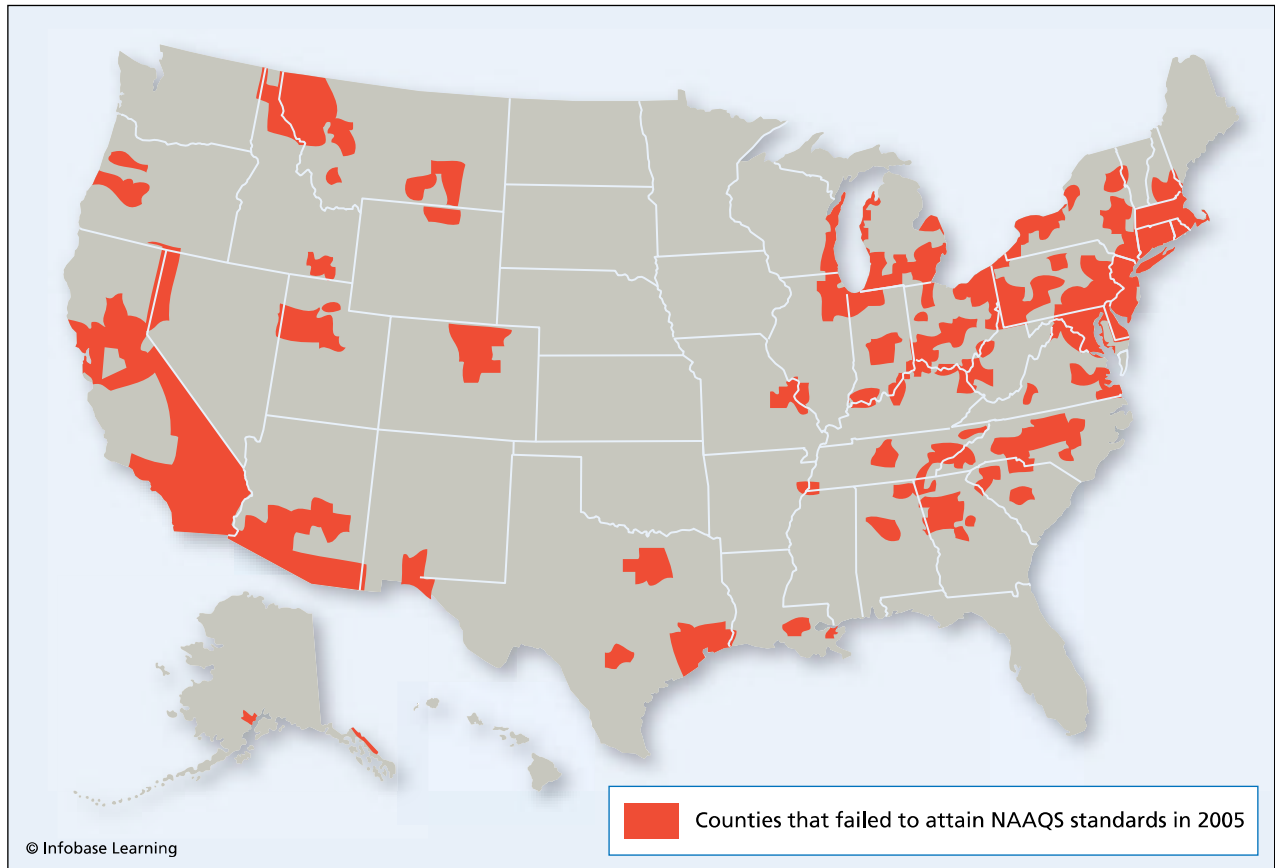
passage of a major set of amendments that created very demanding new emission standards for both stationary and mobile sources. The 1970 amendments also allowed enforcement and inspection programs to be conducted at the state level and increased funding related to air pollution control research.

Over the next 20 years, industrial America struggled both technologically and financially with the ambitious goals and deadlines of the 1970 Air Pollution Control Act. By 1990, the federal government decided the country was ready for the next step in improving air quality. The 1990 Clean Air Act Amendments included tougher air-quality standards and motor vehicle emissions, mandated the study and eventual use of alternative (nonhydrocarbon) fuels, and required the elimination of certain types of toxic air pollutants, control of acid rain, and phaseout of chemicals that were causing reductions in stratospheric ozone levels.

For pollutants where the scientific evidence was sufficient to establish a genuine concern that they might be harmful to public health or environment, the 1990 Clean Air Act required the U.S. Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS). This was done for six pollutants called criteria pollutants. The Clean Air Act as amended in 1990 (often abbreviated CAA) required EPA to develop regulations to monitor and control the discharge into the atmosphere of pollutants that pose unacceptable health or environmental risks. The CAA created two types of NAAQS for the criteria pollutants considered harmful to public health and the environment:

1. *primary standards*—designed to protect public health, including "sensitive" populations: asthmatics, children, and the elderly
2. *secondary standards*—created for the protection of air clarity (reduction of haze), animals, crops, vegetation, and buildings

The standards are stated in maximal concentrations allowed on an hourly, quarterly (three-month), or annual (yearly) average basis as measured in parts per million (ppm) by volume, milligrams per cubic meter of air (mg/m<sup>3</sup>), and micrograms per cubic meter of air (mcg/m<sup>3</sup>). For each of these pollutants a mandatory, federally enforceable maximal concentration has been set that any stationary source may not exceed. Primary standards are those limits designed to protect public health directly. This includes particularly sensitive populations, such as people who have chronic lung disease (asthma), children, and elderly



**A map of the United States showing areas that failed to meet the EPA National Ambient Air Quality Standards in 2005**

adults. Secondary standards are those that seek to control pollutant discharges at concentrations that may decrease visibility or damage animals, crops, vegetation, or buildings. Areas where concentrations of one or more of these criteria pollutants exceed NAAQS are designated as nonattainment areas, and local governments must develop plans to reduce or control pollution levels to make the area in compliance with NAAQS.

Not included as part of the NAAQS is a class of compounds called toxic air pollutants, also called Hazardous Air Pollutants, or HAPs. These are substances that, when discharged into the atmosphere, have been linked to severe health effects including cancer or birth defects and/or environmental damage including destruction of vegetation or degradation of soil and water quality. Compounds such as benzene, present in gasoline; perchloroethylene from dry cleaning; and methylene chloride, a solvent and paint stripper, are examples of common HAPs along with dioxin, asbestos, and metals such as cadmium, mercury, chromium, and lead.

The 1990 Clean Air Act lists 188 HAPs, and EPA has developed a two-phased approach to their regula-

tion. The first phase is a technology-based method, which consists of the development of Maximum Achievable Control Technology, or MACT, standards. These standards require a business or company discharging a HAP into the atmosphere to meet emission limits based on levels already being achieved by similar sources elsewhere in the country. In the next phase, the EPA applied a risk-based approach. This was done to identify whether technology-based emission limits were sufficient to manage the health and environmental risks associated with HAP emissions. Once this was completed, the EPA developed more stringent standards for certain HAPs to control any remaining or residual health/environmental risks.

*See also* AIR POLLUTION; ASBESTOS; BENZENE; CHROMIUM; DIOXIN; LEAD; MERCURY; NOX; OZONE; PARTICULATE; SULFUR DIOXIDE.

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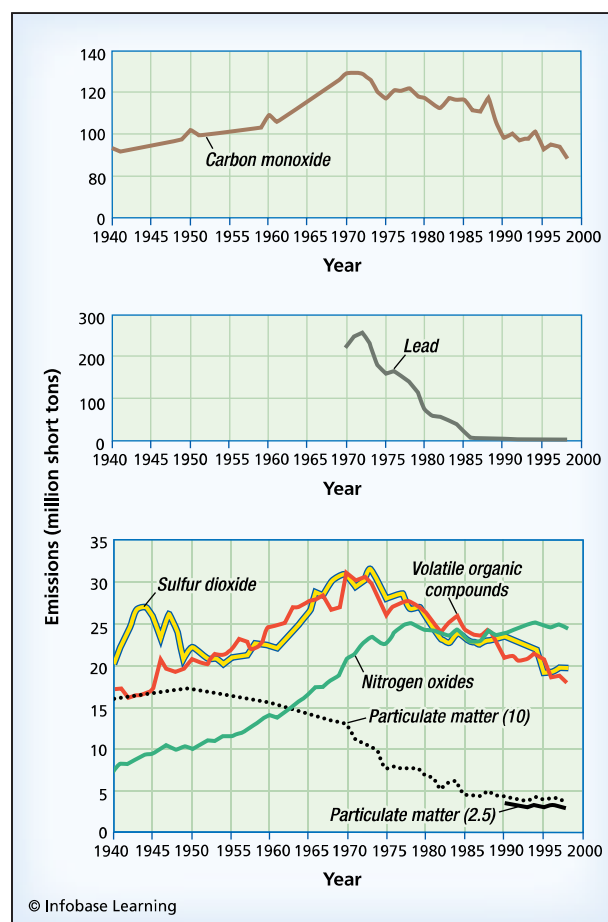
**air pollution** Any input of chemical, aerosol, or particulate that is not found as a significant component of everyday air is considered to be air pollution. This definition allows for vast numbers of pollutant types and chemicals. At any time and anywhere, there are bound to be vast amounts of contaminants in the air, but it is rare for them to reach significant and especially unhealthy concentrations. Certainly, since the beginning of the Industrial Revolution, the amounts and varieties of air pollutants have increased exponentially, at least until 1970, when the Clean Air Act was signed into law. It was once assumed that the oceans would modulate most of the anthropogenic additions to the atmosphere, but that theory eventually was proven wrong when significant amounts of anthropogenic air pollutants found in glacial ice and atmospheric components of gases such as carbon dioxide showed dramatic increases (e.g., the “hockey stick” graph of Al Gore).

The Clean Air Act identified six “criteria” air pollutants, namely, carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide, as those in most dire need of reduction. The most widespread danger of these to human health is ground-level ozone, although all can cause adverse health effects. Part of the chemical makeup of each of these “criteria pollutants” has natural sources (forest fires, volcanoes, etc.) and part is anthropogenic; some sources (natural or anthropogenic) contribute more than others. Since 1970, the concentrations of most “criteria pollutants” have diminished in the air across the United States to varying degrees. In 1990, the U.S. Congress revised and expanded the Clean Air Act, establishing stricter standards for criteria pollutants. As a result, numerous cities or urban regions were unable to meet these new, stricter standards and are now being faced with an obligation to improve their air quality further. Many have never been able to meet the 1990 standards consistently. There were also several amendments that placed an emphasis on more cost-effective methods to reduce air pollution. In 2007, carbon dioxide was also declared an air pollutant even though it is a natural by-product of respiration of numerous organisms. The reason for

its change of status is that it is the main greenhouse gas implicated in global warming, and there is a tremendous amount of anthropogenic carbon dioxide being emitted to the atmosphere.

The quality of air in the United States has greatly improved since the Clean Air Act was enacted in 1970. Europe, Japan, and several other industrialized nations also have cleaner air as the result of similar governmental legislation. Even with the efforts of these nations, however, global air quality has continued to decline, with no indication of a reversal in the near future. China now has 16 of the 20 most polluted cities in the world, and several cities in India have also become severely polluted. Until these huge countries with massive populations, as well as the numerous smaller, less-developed countries, begin to curtail their pollutant discharges to the atmosphere, conditions will not improve.

Air pollution can be subdivided in many ways by source, components, and mode of formation. The first major division, however, is whether it is primary or secondary.



**Graphs showing the concentrations of the six criteria air pollutants in the United States from 1940 to 2000**

## AIR POLLUTION IN NATIONAL PARKS

The first national park in the United States was Yellowstone, established, in 1872 by an act of Congress. Tucked into the northwest corner of Wyoming, Yellowstone National Park encompasses 3,500 square miles (9,065 km<sup>2</sup>) of mountains, streams, and forests that is home to a wide variety of charismatic megafauna: grizzly bears, wolves, bison, and elk. Within the park are Old Faithful and a collection of other extraordinary geysers, hot springs, geothermal vents, and special geological features including the Grand Canyon of the Yellowstone, a deep gorge cut into bedrock by the Yellowstone River.

Since the creation of the National Park Service in 1916, the United States has dedicated 80 million acres (324 million ha) of unique natural resources and historic places, which includes almost 400 sites ranging from untouched wild and scenic rivers to handicap-accessible urban parklands and well-developed shorelines. They represent the “crown jewels” of the nation, open to all and held forever in trust for the public’s enjoyment. The parks are divided into several categories.

Unfortunately, the parklands do not exist in either a cultural or a geographic vacuum, and with almost 300 million people visiting the nation’s battlefields, monuments, and scenic areas every year, they are susceptible to many of the ills inherent in modern society: crime, overcrowding, and pollution, particularly air pollution. Many, if not most, of the national parks are still some of the most environmentally pristine places in the country, but air pollution from surrounding, more developed and urbanized areas can intrude on

the public’s expectation of clean air. Air quality in the national parks first surfaced as an issue in the 1950s, and since then the National Park Service has been struggling to monitor and control the following three basic types of air pollution: haze, ozone, and acid rain.

### HAZE

Caused by fine particulate suspended in the air, haze interferes with local visibility and detracts from the panoramic vistas and scenic wonders of many national parks. The absorption of light, also called light extinction, not only reduces visibility, but also decreases or bleaches out the sharpness and vividness of natural colors. The white haze present almost year-round in Great Smoky Mountains National Park, Tennessee, reduces the average visibility to 24 miles (39 km), whereas the expected natural (unpolluted) visibility should be 93 miles (150 km). The decrease is due to the light scattering and adsorption effects of very small (micrometer) sized particles and gases (aerosols), primarily fossil fuel combustion by-products such as sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>). These particles are blown into the park by eastern coal-fired power plants that lack adequate air pollution control devices.

### OZONE

Ground-level ozone is produced by the chemical reaction of nitrous oxides (generated by the burning of

*(continues on page 20)*



Evening haze over Grand Canyon (Tony Wear, 2008; used under license from Shutterstock, Inc.)

U.S. NATIONAL PARKS			
Type	No.	Description	Example
International historic site	1	Sites with special, multinational significance or status.	Saint Croix Island International Historic Site, Massachusetts. Halfway between the equator and the North Pole, this site commemorates the attempted French settlement of North America.
National battlefields, memorials, and associated military parks	52	Sites that commemorate or honor a historic person or event.	Flight 93 National Memorial commemorates the passengers and crew of Flight 93, who, on September 11, 2001, gave their lives to thwart a planned attack on the nation's capital.
National historic site	78	A place that is associated with a person or subject of historical interest.	Edison National Historic Site, New Jersey. The research and development laboratory as well as residence of the famous inventor
National historical parks	42	Applies to multistructures or parcels that incorporate more than a single property or building.	Boston National Historical Park, Massachusetts. Associated with the American Revolution. Sites include Bunker Hill, Dorchester Heights, Old North Church, and Paul Revere House.
National lakeshores and seashores	14	Shoreline areas adjacent to the Great Lakes and inland water bodies. Some have facilities for use by the general public, while others are relatively undeveloped.	Indiana Dunes National Lakeshore. 25 miles of shorefront along southern Lake Michigan. This area contains beaches, extensive sand dune systems, wetlands, and historic sites.
National monuments	74	Landmarks, structures, and other objects of historic or scientific interest situated on lands owned or controlled by the government.	Canyon de Chelly National Monument, New Mexico. Features ruins of prehistoric Native peoples constructed around 1300. Located at the base of cliffs and tucked into canyon wall caves.
National parks	58	Large, natural areas containing a variety of special characteristics, including significant historic features. Consumptive activities (hunting, mining, etc.) are not permitted.	Glacier National Park, Montana. Unspoiled mountainous terrain hosting glaciers, lakes, and streams, as well as many types of unique flora and fauna.
National parkways	4	A roadway and adjoining parallel parkland intended for scenic motoring. These often connect cultural or historic sites.	Natchez Trace Parkway. Road that generally follows a Native American trail (trace) between Nashville, Tennessee, and Natchez, Mississippi
National reserves and preserves	20	Areas with features similar to those of national parks, but where public hunting, trapping, oil/gas exploration, and extraction are allowed.	Yukon–Charley Rivers National Preserve. Established on the Canadian border in central Alaska. This 115-square-mile (398-km <sup>2</sup> ) area encompasses the 1,800-mile (2,897-km) Yukon River and the Charley River basin.

(continues)



<b>U.S. NATIONAL PARKS</b> <i>(continued)</i>			
<b>Type</b>	<b>No.</b>	<b>Description</b>	<b>Example</b>
National recreation areas	18	Urban parklands combining open spaces with the preservation of significant historic resources. Founded in areas that can provide outdoor recreation for large numbers of people.	Santa Monica Mountains National Recreation Area, with 600 miles (966 km) of hiking trails and a 55-mile (89-km) scenic drive across the Santa Monica Mountains, near Los Angeles.
National rivers, including wild and scenic rivers	15	Rivers that possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values. They and their immediate surroundings are preserved in free-flowing, undeveloped condition.	Rio Grande Wild and Scenic River, Texas. A 190-mile (306-km) stretch strip of the Rio Grande (American side) flowing through the Chihuahuan Desert.
National scenic trails	3	A system of linear parklands (more than 3,600 miles or 5,800 km) managed jointly by the NPS and nongovernmental agencies.	Appalachian National Scenic Trail. A 2,100-mile (3,380-km) trail from Maine to Georgia, passing through 14 states.
National seashores	10	Designated areas on the Atlantic, Gulf, and Pacific coasts. Facilities range from handicap-accessible to largely undeveloped. Hunting and fishing may be permitted.	Assateague Island National Seashore, Maryland. A 37-mile (60-km) barrier island that is host to wild horses and more than 300 species of birds.
Other parks (other)	11	Unique or other special sites not otherwise classified.	White House (President's Park), Washington, D.C. Since the early 1800s, serves as the residence and office of the U.S. president.
<b>TOTAL:</b>	<b>400</b>		

*(continued from page 18)*

fossil fuels) with volatile organic compounds (from industrial sources and automotive exhaust) in the presence of sunlight. Ozone also is formed by the release of isoprene, a naturally occurring volatile organic compound released by plants. Ozone contributes to haze and damages vegetation. It penetrates the plants' stomatas during photosynthesis and causes cellular damage. Symptoms of foliar (leaf) overexposure to ozone include changes in plant coloring or pigmentation, premature aging and senescence (reduction in cell division rates), chlorosis (insufficient production of chlorophyll), and necrosis (unintentional cell death).

Ozone-induced foliar injury has been reported within the 35,000-acre (14,164-hectare) Acadia National Park in Maine. Comprising a cluster of islands off the Maine coast, Acadia was established in a wide transition zone between eastern deciduous and

northern coniferous forests. Although there are few major industrial pollution sources within Maine, Acadia is downwind of large urban areas to the south and west. Consequently, high concentrations of air pollutants are blown into the park from these areas. Ozone monitoring at Acadia began in 1982, and since then data indicate numerous violations of the one-hour and eight-hour health-based primary National Ambient Air Quality Standard (NAAQS) for ozone.

#### **ACID RAIN**

When sulfur and nitrogen compounds (released during the burning of coal) combine with water vapor in the atmosphere, they form droplets of sulfuric and nitric acids. As these droplets are washed out as rain, snow, or fog, they increase the acidity (reduce the pH) of streams, lakes, and soil. Acidification of the national parklands presents particular problems because so

many of them are unique, ecologically sensitive areas that are not able to adjust to these types of outside assaults on their environmental integrity. In the mountainous areas of the Appalachian National Scenic Trail, for example, the soil cover is relatively thin and has a limited ability to release enough basic minerals to buffer acidic rains. As soil pH decreases, calcium uptake by plants is reduced, and aluminum, which is toxic to plants, becomes bioavailable. Acid rain can also damage historic monuments, markers, and statuary such as those at Gettysburg National Military Park, among others.

Fortunately, air quality in most national parks is improving. In 1977, the U.S. Congress recognized the need to provide special protection for national parks from air pollution and, as part of the Clean Air Act, designated most national parks, wilderness areas, international parks, and national wildlife refuges as class I attainment zones. This special designation gives state and federal regulatory agencies special authority to prevent future and remedy existing visibility problems that are caused by anthropogenic pollution. Efforts to improve air quality in the national parks have had a mixed record of success because of uneven or inconsistent governmental funding and enforcement priorities.

The Air Resources Division of the National Park Service (NPS) operates a system of air monitoring stations in 70 national parks across the country, many for more than 20 years. This system is designed to measure levels of air pollutants and, at some stations, collect important meteorological information. These data are needed in order to assess long-term trends that may impact parkland ecologies. The informa-

tion collected also helps determine compliance with National Ambient Air Quality Standards (NAAQS) and evaluates the effectiveness of local and regional air pollution control policies and initiatives.

The monitoring programs collect and analyze air samples for three types of pollutants: visibility reducers (fine and coarse particulate [PM<sub>2.5</sub> and PM<sub>10</sub>] sulfate, nitrate, organic and elemental carbon), ozone and other gases, and atmospheric deposition (sulfate, nitrate, ammonium, cations [metals], mercury in precipitation, sulfur dioxide, sulfate, nitric acid, and nitrate). By providing these monitoring data to federal and state regulatory agencies that use them in policy development and enforcement actions, as well as aggressively developing and implementing air pollution control programs within park boundaries, the National Park Service was well on the way to meeting its goal of stable or improved air quality in 70 percent of its monitored parks by 2008. Between 1995 and 2009, 30 reporting parks showed stable or improving visibility on both the clear and hazy days, and 22 of 29 parks showed stable or improving trends in sulfate, nitrate, and ammonium concentrations. Of the 32 park units that monitor ozone, 20 (63 percent) reported stable or improving air quality trends. Overall, 68 percent of parks where air quality monitoring is taking place had stable or improved air quality.

The value of the monitoring program can be demonstrated in the northwestern United States, where a study of regional haze linked visibility-reducing sulfates at Mount Rainier to the Centrailia coal-fired power plant in Washington. The Centrailia plant

*(continues)*

#### AIR POLLUTION CONTROL PROGRAMS AT NATIONAL PARKS

Mount Rainier National Park, Washington, White River maintenance building	Installation of a photovoltaic system to provide solar electricity (47 kW) for the building and associated maintenance operations. The NPS has installed more than 700 photovoltaic systems in its parks, monuments, and other properties.
Zion National Park, Utah, mass transit bus system	Natural gas-fired buses reduced traffic congestion in the park and air pollution associated with automobiles recreational vehicles (RVs), and diesel buses.
Joshua Tree National Park Cottonwood Complex, California	Installation of a hybrid photovoltaic and propane-fired electrical system that eliminated the need to burn 16,000 gallons (60,567 L) of heating oil annually.
Fire management, all facilities	Development of new control burn and fire management techniques/policies, in cooperation with local regulatory authorities, to minimize smoke and haze from these activities.

(continued)

generates approximately 1,340 megawatts, enough electricity to light up a city the size of Seattle. After a year of tough negotiations with plant operators, the NPS, in association with federal and state regulatory agencies, reached an agreement in which the plant upgraded its air pollution control equipment and reduced sulfate emissions from almost 70,000 tons per year (63,503 metric tons per year) to 10,000 tons per year (9,072 metric tons per year). Since then, visibility at Mount Rainier and in other parks of the Pacific Northwest has been improving significantly.

The National Park Service also funds and participates in many short-term studies and monitoring programs designed to gather data on individual parks to address specific questions such as identification of potential air pollution sources or assessment of ecological risks from designated air pollutants. The National Park Service, however, has no authority to enforce air pollution regulations outside the parks or monuments. Although it works closely with EPA and many state environmental agencies and regularly testifies before the relevant congressional committees that develop air pollution policy for the United States, it depends largely on the funding and enforcement priorities of other parts of the government, and the

pressure brought to bear by park users who want to enjoy clean, fresh air during visits.

See also AIR POLLUTION; MERCURY; MUIR, JOHN; NO<sub>x</sub>; OZONE; PARTICULATE; SULFUR DIOXIDE.

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—by Robert P. Blauvelt

### PRIMARY AIR POLLUTANTS

Primary air pollution means that the pollutants in the air have been released directly from their source, without having undergone any chemical reactions of another pollutant to attain their current state. All pollutants from natural sources are primary. The "criteria pollutants" can arise from primary sources, with the exception of low-altitude ozone, which is almost entirely anthropogenic in origin. Particulates are commonly primary, although many are not. Lead is always primary, and sulfur dioxide is mostly primary. Oxides of nitrogen are mixed. Carbon dioxide is overwhelmingly primary, but not completely.

London smog, named because it is so common in London, United Kingdom, is typical of cooler areas that have occurrences of heavy cloud cover or extensive fog (condensed water vapor). It has the appearance of brownish smoke, and smoke is typically a major component of smog (smoke + fog = smog). One of the worst air pollution disasters ever occurred in London in 1952 as a result of primary air pollution. One of the worst air pollution disasters in the United States occurred in Donora, Pennsylvania, and it was also dominantly primary air pollution.

### SECONDARY AIR POLLUTANTS

Secondary air pollutants are those produced from chemical reactions among primary or secondary air pollutants in the atmosphere. The reactions are primarily photochemical, meaning they are driven by strong sunlight. Secondary pollutants are more common in summer, when the rays of the Sun are more direct and the temperature is higher. The most common secondary air pollutant is ground-level ozone. It is produced by a photochemical reaction between volatile organic compounds (VOCs) and oxides of nitrogen. There are many other dissociation reactions requiring strong sunlight that can produce dangerous pollutants. Some photochemical reactions produce free radical ions that actually degrade and reduce dangerous air pollutants. There are secondary reactions that do not require strong sunlight, such as the reaction of sulfur dioxide to sulfuric acid. Instead, they involve reaction with moisture.

Smog that is composed primarily of secondary air pollutants is called photochemical, or Los Angeles, smog because it is so common there. In fact, most of the air pollution in the Southern California cities, as well as Denver, Colorado, is rich in secondary air





Airborne-deposited soot (particulate) accumulates on museum sculpture in London (Heather L. Jones; used under license from Shutterstock)

pollutants. Even though Denver is typically not as hot as Los Angeles, the stagnation of air and strong unimpeded sunlight are ideal for producing secondary air pollutants.

### NATURAL SOURCES

Although air pollution is typically thought of as dark clouds puffing out of a smokestack or an exhaust pipe, much air pollution has natural sources. Although some natural sources of pollution can be exacerbated by human activity, and some can be greatly altered by it, others continue to be unaffected by humans and will be present long after humans are gone. Although there are numerous sources of natural pollutants, from windblown salt spray to methane releases from the ocean floor, this section will consider only a few, namely, windblown dust, fires, volcanoes, biological pollutants, and crossover pollutants

### Dust Storms

Perhaps the simplest type of air pollution is wind-blown particulate. Strong winds passing over open sand or soil can lift tons of fine material into the air

and carry it aloft before depositing it. This suspended material constitutes dust storms and sandstorms, which are common in arid regions. This dust can be carried great distances across areas that produce no particulate. For example, dust lifted from the Sahara in northern Africa can be found as a component of the air pollution particulate in the Caribbean and even into the southernmost United States at times. The dust settles in areas where the wind is gentler or rises. The deposits formed by dust are called loess and can be quite extensive, especially in China.

Windblown continental dust is primarily made of very fine quartz from deserts, but it can also contain many other components, including iron, organic material, calcium carbonate, and even bacteria and other microorganisms. The dust provides nucleation sites for precipitation once it is out of the arid area. Large input of dust in the oceans can affect nutrient cycling and productivity. Inhalation of dust can also cause significant health problems.

Windblown dust is a natural process that would happen with or without the help of humans. Human activity, however, typically exacerbates the situation. The best example of human activity's increasing particulate is the dust bowl of the Midwest in the



Natural air pollution in the form of particulate and smoke is produced by a forest fire (Samuel Acosta; used under license from Shutterstock)



1930s. Poor farming techniques and a particularly dry period caused topsoil to dry out and be subject to wind erosion. Huge black clouds of dust produced darkness during daylight hours in many towns. Overgrazing of areas marginal to deserts removes the vegetation that holds the soil together and allows it to be eroded by wind. Overuse of water for irrigation dries out lakes. The case of desertification around the rapidly drying Aral Sea in the former Soviet Union is the prime example.

### Wildfires

It is questionable whether woodland fires can be considered natural, since so many are started by humans, but certainly, many others are caused by lightning in dry conditions. Fires produce an enormous amount of particulate, both fine and coarse. This is by far the largest component of air pollution from fires and the greatest health hazard. The visual density of the smoke shows the level of particulate, and it can literally turn the sky black and cover the Sun during daylight for many miles around the fire. Particulate can persist for tens to hundreds of miles (kilometers) away from the fire, depending upon its size and intensity as well as wind conditions. Other air pollution components depend upon the conditions of the fire. Typical chemicals released are carbon monoxide, carbon dioxide, oxides of nitrogen, and organic compounds. The organic compounds can be quite variable depending on the type of trees. Polycyclic aromatic hydrocarbons (PAHs) are emitted from all fires, but creosote is much more common from pine forests. Other compounds may include methylethyl ketone (MEK), benzene, toluene, and metals.

### Volcanoes

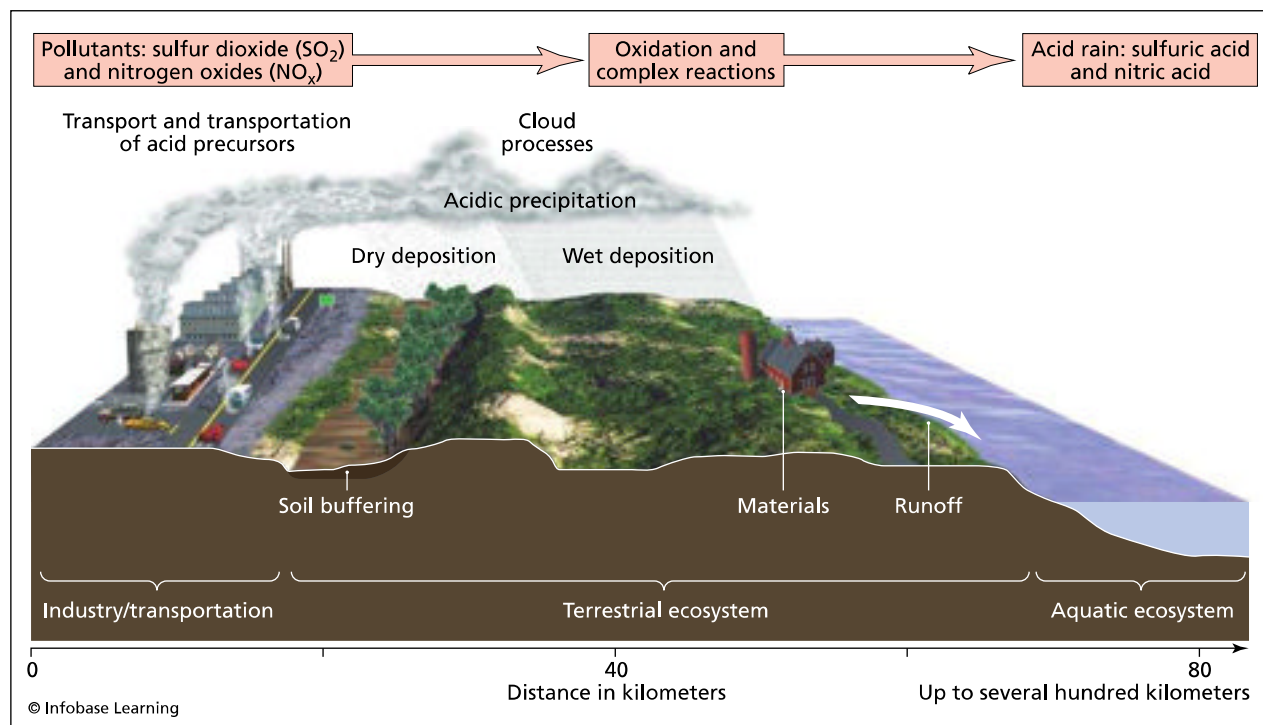
Although they are relatively rare, large volcanic eruptions have the capacity to put more air pollution in the atmosphere in a shorter time than any other source. As in wildfires, the main pollutant is particulate. This particulate in a volcano is pulverized rock and volcanic glass shards in the form of ash. The eruption column from a volcano can extend 45,000 feet (13,846 m) into the atmosphere. The ash not only covers the ground for many hundreds of miles (kilometers) downwind of the volcano, but may also circulate in the higher parts of the atmosphere for years. Although typical small eruptions like that of Mount Saint Helens in 1980 emit  $0.24 \text{ mi}^3$  ( $1 \text{ km}^3$ ) of ejecta (solid material), there have been larger eruptions, such as Tambora in Indonesia in 1815, that produced more than 36 cubic miles ( $150 \text{ km}^3$ ) of ejecta. So much fine ash filled the upper troposphere that it reflected a significant portion of the incident



Unless properly managed, cruise ships can be major sources of ocean pollution. (© Ron Watts/CORBIS)

sunlight back into space. As a result, 1815 is referred to as the “year without a summer,” because it was cold enough to have snow on the ground in June in New England. There was a severe worldwide famine from this event. Even more ominous is the fact that the Tambora eruption was not relatively significant on the Earth history scale. The volcano Toba in Indonesia erupted 74,000 years ago with 700 cubic miles ( $2,800 \text{ km}^3$ ) of ejecta. The climatic repercussions of that eruption must have been incredible.

Volcanoes also emit a significant amount of gas, both during the eruptions and between them. The most abundant gas is sulfur dioxide, which can produce acid precipitation nearby. Hawaii has acid rain problems from nearby volcanoes. Other gases include carbon dioxide, methane, water, and very minor amounts of many other compounds, such as fluorine, chlorine, methyl ethyl ketone (MEK), argon, boron and lithium compounds, benzene, and a huge number of metals. The gases are in such low quantity relative to the ash that they are usually overlooked. The best example of a problem with one of these minor gases occurred in 1783, when the



**A diagram showing generation of air pollutants from industrial and transportation sources, gravitational fallout (dry deposition) and precipitation washout (wet deposition) of acidic components (sulfuric and nitric acid), and transportation of acid into surface water bodies**

Laki eruption in Iceland produced so much fluorine gas that it poisoned hundreds of thousands of livestock and killed 25 percent of the human population on the island.

### ANTHROPOGENIC POLLUTANTS

Pollutants produced by human activity are numerous and diverse. There are a vast array of industrial organic compounds largely used as solvents, plastics, and chemical intermediaries and numerous heavy metals and heavy metal compounds that are mining related and industrial. This section reviews some of the sources of these chemicals, namely, the petrochemical industry, pesticides, transportation, and incineration.

#### Petrochemicals

When crude oil is removed from the ground, it is a mixture of a large number of chemicals with numerous properties. To separate these compounds for use in the various applications, the oil must be processed in a refinery. The main component of a refinery is a distillation tower in which the oil is heated and vaporized. The different densities of chemicals are condensed and removed as a function of height, the lighter compounds rising higher and the heavier

compounds remaining at the bottom (jet fuel at the top, tar at the bottom). This process produces the primary petrochemicals, which then are reacted with other chemicals using catalysts. Many of the distillates are piped to nearby chemical plants, where the petrochemicals are reacted to form still other industrial chemicals.

The easiest way to see the air pollution that is emitted from a refinery is at night when the gas is flared off in a giant flame. But the processes behind this flaring are much more complicated. Virtually all of the chemicals produced in a refinery are volatile organic compounds (VOCs), which are classified on the basis of their ready ability to evaporate. Anytime these chemicals are exposed to air, whether contained or in an accidental spill, fumes are released to the atmosphere.

#### Pesticides

Pesticides primarily enter the air through spraying. Many agricultural applications of pesticide use aerial spraying or crop dusting. Depending upon weather conditions, most of the pesticide settles onto the crops, but a significant amount can evaporate into the air or be blown away. The overspray not only affects areas adjacent to the application, but also can be carried great distances depending upon the



persistence of the compound. The residues of a number of pesticides have been found in glacial ice in the arctic, showing that these airborne pesticides can essentially circle the Earth. The residues in remote areas are in very low concentrations, but near the place of application, they can be quite large. They are removed from the air by direct gravitational settling, or “fall out”; attachment to particulate and settling; washout by precipitation; and chemical reaction with other airborne chemicals, particularly in the presence of strong sunlight. The dominant mode of removal depends upon the pesticide.

More recently, there have been less spraying and more seed application. Many of the pesticides are now systemic and are circulated throughout the vascular system of the plant. This protects the entire plant from attack by insects and fungus and constrains pesticide air pollution. The adverse effects on organisms that consume the plants may be enhanced, since the pesticides cannot be removed by washing.

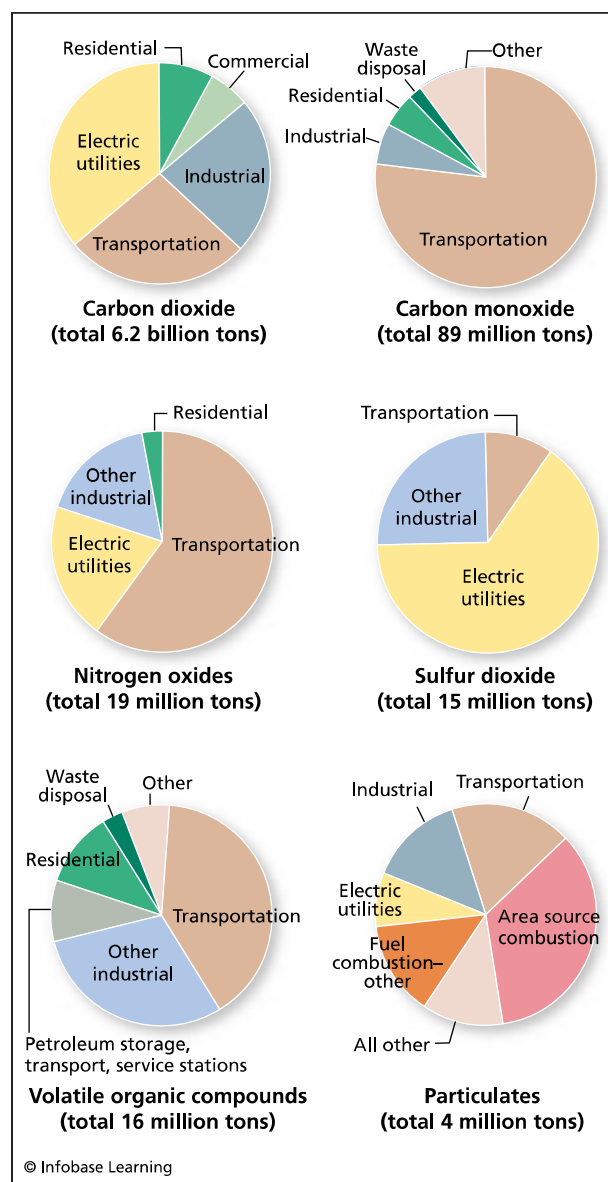
### Transportation

The U.S. Environmental Protection Agency estimates that internal and external combustion engines associated with transportation are the single leading cause of urban air pollution. The burning of petroleum products generates numerous air pollutants, including particulate, carbon monoxide, anthropogenic carbon dioxide, oxides of nitrogen, sulfur dioxide, polycyclic aromatic hydrocarbons (PAHs), and other partially burned hydrocarbons. Previously, lead was also released into the atmosphere by transportation sources, but it has been banned since the 1970s. These primary air pollutants also react to produce secondary pollutants, especially ozone and acid precipitation. The combination of primary and secondary pollutants combine to make urban areas the most high-risk places in the world for respiratory health.

Advances in transportation technology have steadily improved the air quality of urban areas over the past three decades. Catalytic converters, unleaded and oxygenated fuels, and other air pollution devices reduce tailpipe emission of pollutants for most conventional engines and hybrid engines; pressurized natural gas (PNG) and fuel cells reduce the total amount of emissions including secondary pollutants. Improved public transportation and use of trains rather than trucks for freight hauling could greatly improve the air quality, but most areas do not have such systems. In rural areas, the density of polluting transportation sources is low enough that it can generally be dissipated into the atmosphere. As population increases in these areas, they too will face decreased air quality.

### Incineration

Waste is commonly incinerated, especially in rural and suburban areas. This practice is efficient in reducing the volume of the waste, but it greatly degrades air quality. The most abundant pollutant in smoke is particulate. The composition of the particulate varies considerably, depending on what is being burned. The particles are called fly ash and can be dispersed many miles from the source, a smokestack. Fly ash can contain hazardous substances including heavy metals such as lead, chromium, and arsenic and organics such as PAHs, polychlorinated biphenyls (PCBs), and dioxin. Even in small amounts,



Pie charts showing the sources of major air pollutants and relative amounts averaged from 1990 to 1998

these substances can cause health problems for susceptible people. For this reason, there are now federal and many local statutes controlling the amount and composition of smokestack emissions. They must be fitted with pollution-reducing devices, generally scrubbers, and they are permitted to release only a given volume of emissions, depending upon the local environment and the type of emissions.

See also BENZENE; CARBON DIOXIDE; CARBON MONOXIDE; CREOSOTE; DESERTIFICATION; DUST BOWL; MEK; OZONE; PARTICULATE; SOIL; VOLCANOES; VOLATILE ORGANIC COMPOUND.

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**aldrin/dieldrin** Second only to dichlorodiphenyltrichloroethane (DDT) in application, aldrin/dieldrin are powerful and formerly widely used pesticides that were also irrevocably banned. They seem to have escaped the notoriety of DDT, even though they are more toxic. They did not go entirely unnoticed in popular culture, however, as they were used as a murder weapon in an episode of the popular television series *Law and Order: Special Victims Unit*. Invented in the 1940s, aldrin and dieldrin were used extensively throughout the 1950s and 1960s, achieving peak production of about 20 million pounds (9.1 million kg) per year by the late 1960s.

Aldrin and dieldrin are actually two separate but structurally similar compounds that were both used as insecticides. Aldrin is really not very dangerous as is, but it readily breaks down to dieldrin, both in the natural environment and in insects and other life-forms. Dieldrin is highly toxic to most life and has extreme persistence in the natural environment. Trade names for aldrin include Aldrec, Aldrex, Drinox, Octalene, Seedrin, and Compound 118, and dieldrin was sold as Alvit, Dielatrix, Octalox, Quintox, and Red Shield. Aldrin has been found in

207 of the first 1,613 U.S. Environmental Protection Agency (EPA)–designated Superfund sites on the National Priorities List (NPL) for which it was tested, and dieldrin has been found in 287 of the first 1,613 sites. Aldrin is number 24, and dieldrin is number 17 on the 2007 CERCLA Priority List of Hazardous Substances, which includes 275 entries. Both aldrin and dieldrin pose very grave environmental threats.

#### PROPERTIES AND USES

Aldrin and dieldrin are chlorinated hydrocarbons that do not occur naturally. The technical name for aldrin is 1,2,3,4,10,10-hexachloro-1,4,4 $\alpha$ ,5,8,8 $\alpha$ -hexahydro-1,4-endo,exo-5,8-dimethanonaphthalene, or HHDN, and dieldrin is 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4 $\alpha$ ,5,6,7,8,8 $\alpha$ -octahydro-1,4-endo,exo-5,8-dimethanonaphthalene, or HEOD. Both are white to tan powders as chemicals, but, as insecticides, they were marketed as emulsifiable concentrates, wettable powders, dusts, and granules. Aldrin was used as a soil insecticide for beetles, rootworms, and termites. Dieldrin was largely used in agriculture as a soil and seed treatment, as a wood treatment, and as mothproofing for wool, as well as directly on insects such as locusts, mosquitoes, and tsetse flies. Both were used on crops such as corn and cotton and in specific applications for beans, onions, sugar beets, nursery stock, and ornamental and fruit bushes and trees, among others. In 1970, the U.S. Department of Agriculture banned all uses of aldrin and dieldrin because of their toxicity, but, in 1972, EPA approved the use of these pesticides for residential and commercial control of termites. This practice continued until 1987, when even this use was banned and the manufacturer voluntarily stopped production.

#### ENVIRONMENTAL RELEASE AND FATE

As with most pesticides, both substances were ultimately released into the environment, generally entering the soil and groundwater as nonpoint source pollutants. Now, since the ban has been enforced, they only leak from storage facilities and waste sites. From a regulatory standpoint, current discharges are considered to originate as point source pollutants. This is because they were used on specific locations for a specific purpose (such as agricultural fields). Industrial releases of aldrin in 2005 totaled a mere 3,440 pounds (1,564 kg) with no reports of dieldrin release. It would appear that aldrin and dieldrin should no longer be substances of concern, but in fact almost all Americans are still exposed to them on a regular basis. There is probably very little aldrin

left in the natural environment, because sunlight, bacteria, insects, and animals convert it to dieldrin. Dieldrin, however, is one of the most persistent environmental contaminants known and among the top 10 percent in terms of danger to the ecosystem and human health. The estimated half-life for dieldrin is from 175 days to more than three years, but it is still found in the soils to which it, or aldrin, was applied some 37+ years later. When they were applied to soil, some aldrin and dieldrin evaporated slowly into the atmosphere, aldrin a bit more quickly than dieldrin. Most of that which evaporated attached to dust particles and was widely distributed. The aldrin converted to dieldrin and dieldrin changed to photodieldrin within a few days. That which remained in the soil attached strongly to soil particles and remained fixed indefinitely. Very little, if any, leached into the groundwater system, and very little has ever been found there. In surface water, that dieldrin which did not evaporate attached to particles and settled into the sediment and remained fixed.

Plants provide the only way to remove dieldrin from soil and sediments. They absorb it through their roots and spread it throughout the plant. Animals can then eat the plants and ingest the pesticide. Dieldrin is highly toxic to bees, aquatic organisms, birds, and especially mammals. It collects in their fatty tissue among other organs and can be passed to humans in both meat and vegetables. It also collects in the fat of human breast milk, where it has been known to concentrate at 10 or more times ambient levels. It was found in 99 percent of breast milk samples from around the world in a survey taken during peak usage. Shellfish that filter sediment can also accumulate dieldrin. These two sources are the main way it enters the human body.

### HEALTH EFFECTS FROM EXPOSURE

There are many adverse health effects of dieldrin exposure. Acute exposure is marked by symptoms of the central nervous system including dizziness, headache, irritability, and periodic and continuous convulsions, leading to possible brain damage, coma, and death if the dose is high enough. It can also cause nausea and vomiting. Long-term chronic exposure has similar effects, as well as kidney and liver damage, tremors, muscle spasms, depression, anxiety, sleep disturbance, impaired memory, weight loss, weakness, immune system damage, infertility, damage to developing fetuses, high infant mortality, and a strange condition in which the body destroys its own red blood cells. The EPA and Department of Health and Human Services have designated aldrin and dieldrin as probable human carcinogens. It has

been shown to increase the incidence of tumors of the kidney, lungs, liver, mammary glands, and lymphatic system of laboratory animals, but most were benign. Only the liver was found to be cancerous in mice but not in other animals.

### REGULATION ON HUMAN EXPOSURE

Aldrin and dieldrin were among the earliest regulated environmental substances. The EPA limits aldrin and dieldrin in drinking water to very low levels: 1 and 2 mcg per liter, respectively, under the Safe Drinking Water Act. If one pound (0.45 kg) or more is released to the environment, EPA requires reporting to the National Response Center. The Occupational Safety and Health Administration (OSHA) set its permissible exposure limit (PEL) at 250 mcg of aldrin and dieldrin per cubic meter of workplace air for an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set the same 250-mcg limit for 10 hours, as well as an Immediately Dangerous to Life and Health designation of 25 and 50 mcg of aldrin and dieldrin, respectively, per cubic meter of workplace air. By 2003, more than 50 countries had banned or severely restricted the use of aldrin and dieldrin, and 100 countries banned the import of these pesticides. The result of the regulations is that the concentration of aldrin and dieldrin in breast milk has been reduced at least 75 percent and commonly 90 percent from its late-1960s levels.

*See also* CHLORINATED SOLVENTS; DDT; PESTICIDES.

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### **Amoco Cadiz oil spill Ouessant, France (March 16, 1978) Water Pollution**

Amoco (American Oil Company–Standard Oil of Indiana) had major operations in oil transportation operating under the name of Amoco Tankers and Amoco Transport. As Middle Eastern oil started to become a significant factor in the market, the company commissioned the construction of two supertankers to establish a strong position in transportation. A supertanker is a vessel that is capable of carrying more than 2 million to 3 million barrels (318 million–477 million L) of crude oil. The shipbuilder, Astilleros Españoles, S.A., the same company that had constructed the *Nina*, *Pinta*, and *Santa Maria* for Christopher Columbus, laid the keel for the first of the Amoco's tankers the *Cadiz*, named after the town in which it would be built. Construction of the *Amoco Cadiz* began in May 1970 and took four years to completion. The ship was almost 1,100 feet (338 m) long and 170 feet (52 m) wide, so large that three college football games could be played simultaneously on its decks, with plenty of room to spare. It had a cargo capacity of 234,000 deadweight tons (213,000 metric tons) and could carry 1.6 million barrels (67 million gallons, or 255 million L) of crude oil. Powered by a 30,000-horsepower diesel engine driving a single screw or propeller, the *Cadiz* could travel at up to 15 knots (28 km/h, or 17 miles per hour) and required a crew of only 44 to operate it.

During shipbuilding, both Amoco and the American Bureau of Shipping (ABS) conducted regular inspections and testing of equipment, both to ensure conformance with design specifications and to make necessary changes required during construction. The ABS is a not-for-profit organization that develops and evaluates rules and standards for shipbuilding, including operating designs and eventual seaworthiness. Even for such a huge size, the *Cadiz* was steered by a single, hydraulically driven rudder. In its simplest form, a rudder is a flat piece of metal or wood mounted vertically to the bottom of the ship that can be turned to the right (starboard) or left (port) by a helmsman and is used to redirect the flow of water past the hull. When under way, the ship moves in the same direction as the rudder is turned.

The rudder on the *Cadiz* was a massive device and could only be turned by using a specially designed

hydraulic steering engine. This engine operated two pairs of rams, or metal pushrods, sealed inside four fluid-filled cylinders. The four steel rams had cast-iron tops, or heads, that mechanically adjusted or pushed the rudder in the direction determined by the helmsman. When a course correction or docking maneuver was required, the helmsman (or autopilot) turned the wheel, producing an electrical impulse that was transmitted to a set of hydraulic pumps. These pumps added or removed hydraulic fluid from the ram cylinders, which, in turn, changed the position of the rams, and the ship changed course as the rudder moved.

The hydraulic steering system was a critical safety feature and vital to the ship's survival. Without the constant pressure of hydraulic fluids in the cylinders, which kept the rams pressing against the rudder linkage, the steering of the ship could not be controlled. No backup or secondary maneuvering systems were designed or installed in the *Cadiz*. On twin or dual screw ships, if the rudder fails, the vessel can still have limited maneuverability by the helmsman's varying the speed and direction (forward or reverse) of the propellers. The *Cadiz* had only one screw and only one rudder. Even the *Cadiz*'s anchor was too small to be useful in stopping the ship, designed only to hold her steady during loading and unloading.

The *Cadiz* was placed into service in 1974. The ABS had certified all components of the ship, including its hydraulic steering system, as seaworthy. Periodic inspections by ABS over the next three years did not find any major problems with the rudder control mechanisms. Almost immediately, the *Cadiz* was chartered to Shell International Petroleum Corporation to move petroleum from the Middle East to refineries in Europe. Under the terms of the charter, Amoco was responsible for the ship's maintenance, and, when it was being serviced or repaired or was inoperable because of equipment failure, no payments were to be made by Shell to Amoco. Under this arrangement, it was in Amoco's best interest to keep the *Cadiz* in service as much as possible. Even though the vessel was originally scheduled to be dry-docked every year for major repairs and overhaul, Amoco decided to extend these service intervals to every 30 months, thus saving hundreds of thousands of dollars in dry-docking and charter fees.

### **THE ACCIDENT AND SPILL**

In February 1978, a full load of crude oil was pumped into the huge cargo holds of the *Cadiz* from storage terminals, first, at Kharg Island, Iran, and then at Ras Tanura, Saudi Arabia. The ship sailed southward, through the Red Sea, down the east



coast of Africa, around the Cape of Good Hope, and then northward, up the west coast of Africa toward Europe and Rotterdam, its final destination. Representatives of Marine Safety Services, a British company conducting training and safety classes in ship operations for the *Cadiz* officers and crew, were on board. On March 15, within a day or so of its destination, the weather deteriorated, and the *Cadiz* began to roll and pitch in heavy seas. By the next day, the waves and winds were near hurricane conditions. Despite the storm, the ship performed flawlessly, with the helmsman firmly in control of her speed and direction.

On the morning of March 16, just as the *Cadiz* entered the English Channel off the northwest Breton coast nine miles (14.4 km) west of the French island of Ouessant, a series of events took place in the engine room that resulted in the catastrophic failure of the steering control mechanism. After a call from the bridge to the engine room that the ship did not seem to be responding, crew found that five of six bolts on the flange of a hydraulic oil pipe on the port-side steering pump had been sheared off. Hydraulic fluid was gushing from the pipe, and air was entering the steering system. As hydraulic fluid continued to leak from the pipe, the rams that maintained control of the ship's rudder began to lose pressure. Without the rams to control its movement, the rudder began to shift back and forth in the rough seas. As the crew worked frantically to repair the leak and purge air from the steering system, another hydraulic pipe failed, and the rudder, now completely out of control, swung violently back and forth, tearing apart the steering control mechanism and sending metal shrapnel flying throughout the engine room. One crewman was injured, and the chief engineer ordered the engine room evacuated. He then informed the captain that the steering mechanism could not be repaired and that the ship was out of control. The captain radioed for assistance, and the *Pacific*, a German salvage tug, responded.

When a ship, her cargo, or her crew is in danger, the owner or master of the ship can call for help from a marine salvage vessel. These large and powerful oceangoing tugs or repair ships put themselves in peril for a percentage of the value of the ship and/or the cargo being saved. Salvage can take the form of refloating a grounded ship, patching a breach in the hull, repairing a critical mechanical system, or towing a disabled ship to a port or dry dock. Within the last 30 years or so, the definition of salvage has expanded to include protecting the environment by preventing or minimizing the release of a ship's cargo, especially if it is oil or some other substance that might damage the marine environment.



The oil tanker *Amoco Cadiz* sinks off the coast of Brittany, France, on March 16, 1978. (NOAA)

The captain of the *Pacific* offered salvage assistance to the *Cadiz* under the terms of a Lloyd's Open Form (LOF) "No-Cure-No-Pay" contract. The main principle of this contract is that if the *Pacific* failed to save the *Cadiz*, the *Pacific* would not be entitled to any compensation, even if the *Pacific* were damaged or sunk during the salvage attempt. Also, under the Lloyd's Open Form, the price or payment for salvage assistance is decided after the damaged vessel has been secured safely and the parties can more calmly discuss the basis for the claim. In the case of the *Cadiz*, given the value of the ship and its cargo (about \$40 million), the monetary worth of the salvage claim would have been significant.

Before the captain of the *Cadiz* could accept assistance from the *Pacific*, he had to call Amoco's headquarters in Chicago for permission. As the parties negotiated, the *Cadiz* drifted closer and closer to the rocky coastline. Finally, after more than four hours of negotiations and when the *Cadiz* was only six miles (9.6 km) from Ouessant, an agreement was reached and the *Pacific* began salvage operations. Approaching the *Cadiz* through very rough seas, the *Pacific*, with the help of some brave *Cadiz* crewmen, was able to secure a towline to the bow. However, by now the *Cadiz* was pitching and rolling so violently that the bow would disappear below the surface, and the *PACIFIC*'s attempts to turn the *Cadiz* into the wind and tow her a safe distance out to sea were unsuccessful. The towline snapped, as did a second one that was attached to the stern of the *Cadiz*.

By now, the currents and winds had pushed the *Cadiz* up against the coast, and it began to roll and pound against the rocks and shallow bottom of the shoreline. The *Pacific* had to break off the salvage attempt, and at 9:40 p.m. the *Cadiz*'s hull stove in

and the *Pacific*'s captain's log noted that the air began to smell of oil. The crew was evacuated by helicopter, except the captain and one senior officer, who were taken off the next morning. An estimated 15 million gallons (68 million L) of crude oil was released from the *Cadiz* within 24 hours of its grounding. Eight days later, the *Cadiz* had been torn into pieces and spilled its entire 60-million-gallon (227-million-L) crude oil cargo onto the coastline of Brittany, one of the most ecologically sensitive and popular vacation places in France. Eventually, using depth charges, the French navy destroyed the remaining pieces of the wreck as a hazard to navigation. Later, Amoco would sue the owners of the *Pacific* for failing to rescue the *Cadiz* and for not preventing the oil spill. The French courts dismissed the claim.

### **CLEANUP AND ENVIRONMENTAL DAMAGE**

The oil slick from the *Cadiz* eventually covered 25 percent of the Breton coastline, extending 80 miles (128 km) in length and 18 miles (29 km) in width. More than 4,000 people and 50 ships participated in cleanup operations, which took more than six months. Both the British navy and the French army, along with hundreds of volunteers from all across France, used heavy machinery, shovels, and sometimes mops and buckets to remove 220,000 tons (199,600 metric tons) of oily waste the color and consistency of chocolate mousse that had covered the beaches. The oil destroyed the delicate ecosystem along the coastline, obliterating oyster and lobster beds. Thousands of seabirds died, and 30 percent of France's seafood supply was put at risk of contamination. In addition, kelp and algae that usually were harvested for fertilizer and animal feed supplements were destroyed. The overall loss in terms of fishery and tourism was an estimated \$100,000,000.

Cleanup was helped by waves and winds that dispersed and evaporated much of the oil. These same waves and winds that pushed the *Cadiz* to her destruction also helped provide nutrients and oxygenated water to the naturally occurring bacteria that slowly biodegraded the oil. Within three years of the *Cadiz*'s grounding, most of the major effects of the oil spill were not noticeable along the coastline. Oil that had been pushed into more protected inlets, however, could still be detected more than 10 years after the spill.

### **THE AFTERMATH**

The proximate causes of the spill were a failed hydraulic line and bad weather. The investigations carried out during the subsequent legal actions and

lawsuits associated with the wreck of the *Cadiz*, however, revealed a much larger, systemic problem with Amoco's policies relating to the design, operation, and maintenance of the ship.

Cast-iron metal bushings (sleeves) were used to line the cylinders that the steel rams of the rudder control traveled through. Cast iron is harder than steel, and as the rams moved back and forth through the bushings, dirt trapped inside the cylinders scored or grooved the surfaces, causing a drop in hydraulic pressure and steering mechanism efficiency. Amoco was aware of the potential problems caused by the cast-iron bushings but had elected to accept a partial refund from the shipbuilder rather than take the ship out of service to replace the bushings. In fact, a replacement set of bronze bushings was onboard waiting to be installed when the *Cadiz* went aground.

Amoco also did not regularly follow manufacturer recommendations that the ram cylinder isolation valves be exercised (opened and closed) and lubricated periodically. If these valves had been working, the engine room staff would have been able to shut down part of the hydraulic steering mechanism and perhaps damp or "brake" the runaway rudder with the remaining functioning rams. Divers recovered the open cylinder isolation valves from the sunken wreck of the *Cadiz*, and French inspectors found that the stem threads had been painted. The valves could not be fully closed because of the presence of this paint on the thread mechanism.

Hydraulic oil should have been properly filtered before being added to the reservoir tank. The in-line oil filters needed to be checked to make sure they were functioning properly, and the oil had to be tested for the presence of water and other contaminants. The reservoir tank also had to be emptied and cleaned periodically to prevent the buildup of sludge. Amoco did not follow any of these maintenance recommendations, primarily because they would have required an interruption in ship's operations. The continued use of impure and partially spent hydraulic oil decreased the system's lubricating ability and probably contributed to the failure of steering controls. A blockage in one of the steering mechanism valves clogged the system. Hydraulic fluid added by engine room mechanics during their attempts to replace the oil being lost through the broken flange simply overflowed out of the top of the reservoir tank. Investigators also found that the crew had not been trained in these and other maintenance procedures, and they had never been drilled in emergency procedures related to a rudder system failure.

These and other operational and maintenance lapses were the direct result of Amoco's unwillingness to accept the loss of income that would

occur during dry-docking and overhaul downtimes. The U.S. courts admonished Amoco for their frugal approach to operations and in a 1988 settlement awarded France \$85.2 million in damages. Both sides appealed, and, in 1990, the courts agreed that the monetary award should be increased to \$120 million. Since then, Amoco and its later owner, BP, have worked to improve maintenance procedures and crew attitudes toward tanker safety.

See also CONTINENTAL SHELF; OIL SPILLS.

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**Anniston Army Depot Anniston, Alabama (1990–1997) Soil Pollution** Anniston is a small town in northeastern Alabama, about 110 miles (177 km) west of Atlanta, Georgia. It is host to a 15,000-acre (6,070-ha) state-of-the-art industrial center with more than 2,600 employees, 260 miles (418.4 km) of roads, and almost 90 miles (144.8 km) of fence line. Since February 1941, Anniston Army Depot has been storing, managing, repairing, and overhauling munitions, including missiles and artillery, small arms, and combat vehicles, including tanks and trucks. The depot contains an ammunition storage area, an industrial plant where most of the vehicle maintenance and equipment restoration activities take place, and an administrative/housing area. The 1,300 ammunition storage bunkers make up more than 90 percent of the site, with the industrial area occupying about 500 acres (202 ha) in the southeast corner of the facility.

The ongoing work at Anniston is essential to national defense and involves the use of degreasers, paints, acids, and solvents as well as petroleum

products such as lubricating oils and fuels, heavy metals, and explosive compounds. Until the early 1980s, facility operators followed standard industrial practices and disposed of most of the wastes generated at the site by burying or placing them in landfills and trenches, sometimes after performing rudimentary processing or treatment and detoxification in lagoons or sumps. Many of these materials, or their breakdown products, have migrated from these landfills and trenches and contaminated soil and groundwater at the site. Since 1981, the Anniston Army Depot has shipped its hazardous waste to licensed off-site disposal facilities.

#### POLLUTED SITES

The long and challenging process of identifying and remediating contaminated soil and groundwater at Anniston began in the 1980s as part of the U.S. Army's nationwide Installation Restoration Program. Working in close cooperation with the U.S. Environmental Protection Agency (EPA) Region IV office and the Alabama Department of Environmental Management, the Anniston Ammunition Depot began to address the approximately 90 waste disposal areas on the property, including spill areas, landfills, and chemical lagoons. There were also several specific polluted sites noted, as follows:

- *Valve disposal pit.* Approximately 10,000 sodium-filled tank engine valves were buried in this pit in 1947. Sodium is a very effective heat transfer fluid but is extremely reactive, especially when exposed to water. Sodium's reaction with water is exothermic and produces very caustic sodium hydroxide and highly flammable hydrogen gas.



**Chemical demilitarization processing facility at Anniston Army Depot, Alabama, 1998** (Robert P. Mayfield/Defense Visual Information Center)



- *Calcium hypochlorite burial pit.* Used for the disposal of 400 100-pound (45.4-kg) containers of calcium hypochlorite. Calcium hypochlorite is an oxidizer and can be a fire hazard when mixed with organic materials. If acidified, it also can release chlorine gas.
- *Chemical disposal pit.* Tanker-truck quantities (2,000–5,000-gallon or 7,571–18,927-L batches) of a variety of chemical wastes were poured into this pit from the late 1940s until possibly as late as 1972.
- *Metal plating shop.* Operations in this building included metal cleaning, treating, and plating. High levels of chromium have been found in soil, surface water, and groundwater adjacent to this structure, possibly released by spills or leakage from waste sumps and carried on dust discharged through the ventilation system.

### REMEDIAL ACTIVITIES

Several remedial activities have been implemented at the Anniston depot. Contaminated soil and sediment has been excavated or dredged from spill areas and streambeds, and sludge from waste pits and lagoons has been removed. A groundwater pump-and-treat system was installed and began operation in 1990 to prevent the off-site migration of groundwater containing organic solvents.

Among the most difficult disposal systems to remediate are the three industrial waste lagoons that stored solvent wastes. These lagoons were closed and backfilled with clay in 1978. About 72,000 pounds (32,659 kg) of trichloroethene (TCE), a volatile organic chemical, is believed to remain in the former storage basins. The highest TCE concentrations (20,100 mg/kg) are present at a depth between eight to 10 feet (2.4–3.1 m). In 1997, Anniston launched a concentrated remediation effort on the contaminated soil in the lagoons. Using 225 injector wells, 109,000 gallons (412,610 L) of peroxide, supplemented with trace concentrations of ferrous sulfate and acid, were introduced into the subsurface over a 120-day period.

Liquid peroxide solution is a quick and often cost-effective method for chemically oxidizing pollutants present in subsurface soil. In this process, hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) generates hydroxyl radicals that directly oxidize soil contaminants. Typically, the peroxide is introduced in a water mixture through specially designed injection wells. In order to accelerate the chemical oxidation, a metal catalyst, most

commonly iron, is added. This mixture of peroxide and iron is known as Fenton's reagent, named after Henry John Horstman Fenton, a Cambridge, United Kingdom, chemist and professor who developed the method in the late 1800s. The combination of iron and peroxide significantly increases the number of free radicals and thus the oxidative power of the solution.

The hydroxyl radicals are extremely strong oxidizing agents, capable of rapidly attacking and breaking the carbon-to-carbon chemical bonds of most organic compounds, usually within minutes after its application. Oxygen is also released during peroxide decomposition and can encourage bioremediation. The effectiveness of Fenton's reagent is tied directly to the permeability and pH of the soil. The higher the permeability, the more quickly the reagent can react with the contaminant. Fenton's reagent loses its effectiveness in calcite-rich alkaline soil. These are soils where carbonate ions ( $\text{CO}_3^{2-}$ ) can rapidly scavenge the hydroxyl radicals as fast as they are produced during the oxidation process.

At Anniston, 25 deep wells were installed to monitor the chemical oxidation process and to serve as a venting system to help ensure an effective radial distribution of the peroxide. Postinjection sampling data indicated that the chemical oxidation process lowered the soil contaminant concentrations from 1,760 mg/kg to below laboratory method detection levels. Data from monitoring wells indicated that migration of contaminants to either surrounding soil or groundwater had not occurred during the remediation process.

Despite these and other cleanup efforts, Anniston Army Depot was added to the National Priorities List (NPL), or Superfund sites, by the EPA in 1989, primarily because of the soil and groundwater pollutants present on the site as a result of its long history of in-ground chemical disposal (1950 through 1981). Remedial activities continue today, and the army estimates that Anniston will be cleaned up and removed from the NPL by 2031.

See also CHROMIUM; ENVIRONMENTAL PROTECTION AGENCY; IN SITU GROUNDWATER REMEDIATION; SUPERFUND SITES; TCE; WELLS.

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**antifouling paint** The hull is the part of the ship that is below the main topside (above water) decking. It generally consists of an outside covering or skin, sometimes called plating, made of wood or metal and an inside framework to which the skin is attached. In most commercial oceangoing vessels, the skin and framework usually are made of steel and connected to each other by welds or metal rivets. An essential part of the ship, the hull keeps the vessel afloat, protects the ship from floating objects that could damage it, and secures the space into which cargo, engines, and other ship's infrastructure are placed.

The outside of the hull also provides substrate for the colonization and growth of both sessile (fixed) and mobile (floating) marine organisms. When these organisms accumulate on the submerged part of the ship to the point where they begin to affect its performance, the hull is said to be fouled.

Hull fouling organisms are those that are typically found in the intertidal and subtidal zones of continuously submerged marine settings. These organisms include arthropoda, such as barnacles, amphipods, and crabs; mollusca, such as mussels, clams, and sea slugs; porifera, or sponges; bryozoa; cnidaria, such as hydroids and anemones; protozoa; marine worms; and chordata, such as sea squirts and fish, as well as seaweed. Fouling organisms tend to concentrate in sheltered areas of the hull, such as sea chest intakes and rudder posts. Sea chests are openings in the ship's hull below the waterline used for the controlled intake and discharge of the ship's cooling system water. Sea chests often have blowout holes through which blasts of air or steam are sent to clear obstructions to water flow. Slow-moving vessels such as towed vessels like cargo barges, floating dry docks, or oil rig platforms are more likely to develop fouling organisms.

Organisms attached to the hulls of ships are a significant problem. Hull fouling increases fuel con-

sumption by as much as 20 percent and can cost a ship's owner thousands of dollars in additional fuel costs. The U.S. Navy spends more than \$200 million every year in extra fuel and maintenance (removal and repainting) related to biofouling organisms. In addition, fouled hulls provide a mechanism for potentially troublesome and disruptive aquatic species to travel from one port to another.

## PROPERTIES OF THE PAINT

Mariners have used a variety of techniques to prevent or at least slow biofouling. Early sailing ships coated their hulls with lime or even arsenic to reduce the attachment and growth of algae and mollusks. Since the 1970s, special antifouling paints (also called bottom paints) have been developed that slowly release a growth inhibiting substance or poison, called organotin or tributyltin (TBT;  $C_{24}H_{54}OSn_2$ ), a substance containing both the metallic element tin and carbon. TBT is chemically bound within the matrix of the paint. As the ship moves through the water, the paint is worn away in a process called self-polishing and the TBT is slowly released. This self-polishing action works even when the ship is moored as long as tidal currents or wave action in the harbor provide sufficient water movement across the hull.

TBT-impregnated paint is used on most commercial and many military vessels. Commercial and recreational marine facilities that routinely wash and repaint ships' hulls use high-pressure cleaning techniques that often flush TBT-bearing paint residuals into harbor or marina waters.

## ENVIRONMENTAL PROBLEMS

TBT recently has come under ecological scrutiny. It is non-water-soluble, or hydrophobic, and it is readily absorbed by marine harbor and ocean water sediments, especially in heavily trafficked ports and shipping lanes. TBT is moderately persistent in sediment, with a removal half-life of months to years, or even longer under anaerobic (oxygen-deficient) settings, and it can be ingested by bottom-dwelling marine organisms. It has been found to bioaccumulate in fish, seabirds, and marine mammals, in which it can damage reproductive or immune systems. It interferes with cell growth, development, reproduction, and immune response and distorts mitochondrial membranes. In marine invertebrates, TBT may alter endocrine (hormonal) functions. A study by the Dutch Institute for Marine Research and the Free University of Amsterdam found TBT and its breakdown products in sperm whale tissues,

suggesting that TBT may be widely dispersed in the marine environment.

These well-documented negative impacts of TBT on marine life have led to an abandonment of its use. As a result, a number of more environmentally friendly alternatives are being developed. The U.S. Navy currently uses copper-based ablative coatings that can be removed or vaporized at high temperatures. These coatings rely on the toxic effects of cuprous oxide to prevent or reduce the growth of marine organisms. This is a short-term solution, as copper-based paints also concentrate in marine sediments and need to be reapplied every two to three years, as compared to about five to seven years for TBT. A more promising bottom paint alternative may be silicone-based coating systems.

See also ARSENIC; BIOACCUMULATION AND BIOMAGNIFICATION; WATER POLLUTION.

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**antimony** Antimony is an inorganic heavy metal that occurs naturally in various rocks and minerals as well as around certain industrial sites and landfills. Antimony ore is mined as the mineral stibnite ( $\text{Sb}_2\text{S}_3$ ), primarily to be mixed with other metals to produce alloys. Alone it is too soft and brittle for most applications, but it can strengthen, harden, and add fire resistance to other materials. It is most commonly mixed with lead to improve battery performance (life and voltage), but it is also used as a primary component in matches, as a lead substitute in solder, in tracer bullets, as a primary flame retardant in numerous items from textiles to plastic toys and covers, in medicines from antiparasite medications in the past to antischistosomal drugs, in the semiconductor industry for numerous applications including diodes and infrared detectors, and in numerous metal

alloys, many with low friction properties. Antimony, however, can be an environmental hazard that has been found to occur in 403 of the first 1,416 U.S. Environmental Protection Agency (EPA) Superfund sites on the National Priorities List. As the result of this widespread distribution as well as adverse health effects from exposure, antimony is ranked 219 of the top 275 most dangerous pollutants on the 2007 CERCLA Priority List of Hazardous Substances.

For economic reasons, very little antimony is mined in the United States. More than 80 percent of all antimony is produced in China; Bolivia, South Africa, Russia, and Tajikistan are the next top producers in decreasing order. Approximately 135,000 tons (122,727 metric tons) of antimony were produced in 2007, up from 106,000 tons (96,364 metric tons) in 1994.

#### ENVIRONMENTAL RELEASE AND FATE

Between 1987 and 1993, nearly 12.5 million pounds (5.7 million kg) of antimony were released into the environment in the United States. The top 10 states reporting antimony releases were Arizona, Montana, Texas, Louisiana, Wisconsin, Missouri, Washington, Idaho, Tennessee, and Alabama. In 2005, some 12,597,353 pounds (5,726,070 kg) of antimony and antimony compounds were reported to have been released into the environment by industry. The industries that release antimony are primarily metal smelting and refining, but also organic chemical production and the manufacture of porcelain plumbing fixtures. Other uses of antimony include petroleum refining, inorganic chemical production, plastics, batteries, and synthetic fibers. Small amounts of antimony also are released by coal-burning power plants and incinerators.

If antimony is discharged in smokestack emissions, particles can attach themselves to other particulate matter and settle to the ground and surface water. Although most sink quickly to the ground, some may remain airborne for longer than one month. Very little antimony can be dissolved in water because of its metallic nature, typically less than five parts per billion (ppb). Usually, it attaches to particles and settles into sediment. Even though it is used for solder in home plumbing, it rarely enters drinking water. It does not appear to bioaccumulate and is seldom found in soil. It exists there typically at concentrations of less than one part per million (ppm). Antimony usually attaches itself to clay and organic material and is not easily dissociated (removed) from these fine grains of sediment and soil. Around antimony processing sites and at industrial waste sites, on the other hand, antimony concentrations have been known to

reach 2,550 ppm, primarily from improper waste management and air pollution fallout.

### HEALTH EFFECTS FROM EXPOSURE

Acute exposure to antimony can produce a number of adverse health effects through both inhalation and oral ingestion. Ingestion of antimony typically causes gastrointestinal distress, including vomiting and diarrhea; respiratory difficulties; and death at high dosages. Inhalation produces the same gastrointestinal response as well as pulmonary edema and death at elevated levels. Contact exposure of antimony has been shown to cause rashes in some test animals and even death in a few cases as well as eye irritations in humans. Long-term chronic exposure to antimony produces respiratory problems including pneumoconiosis and restrictive airway disorders and cardiovascular problems such as changes in blood pressure and electrocardiogram abnormalities. It also has been shown to cause hematologic (blood) disorders, liver and kidney problems, and possible reproductive problems such as alterations in the menstrual cycle and increased spontaneous abortions, as well as decreased life span. Long-term inhalation of antimony has resulted in increased lung tumors in some laboratory animals, but the data are still inconclusive for human exposure.

### REGULATIONS ON HUMAN EXPOSURE

The clear health implications of antimony exposure have led federal regulatory agencies to set recommended limits on exposure to it. The EPA set the drinking water limit at 6 ppb, above which corrective action must be taken. The EPA limit for water in lakes and streams is 145 ppb. There also are limitations on the amount of antimony that can be released to the environment by industry. The Occupational Safety and Health Administration (OSHA) established a limit of antimony in air to 0.5 mg per cubic meter of air during an eight-hour-work day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) similarly recommends a maximum of 0.5 mg per cubic meter of air averaged over an eight-hour workday. They also set a designation of immediately dangerous to life and health (IDLH) of 50 mg per cubic meter of workplace air.

*See also* AIR POLLUTION; INORGANIC POLLUTANTS; LEAD.

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**aquifer** An aquifer is a layer of rock, sediment, or soil or a zone within these layers that is capable of yielding water in large enough quantities to be useful. What constitutes a useful quantity depends upon the need to be served. Some aquifers are hundreds of feet thick and can serve areas the size of states or multiple states, but for a single house, even a small aquifer may be sufficient. In order for the rock or sediment to be an aquifer, it must have porosity to store water, but, most of all, it must have permeability so the water can flow. Water is pumped out of the aquifer through a penetrating well. The water removed must be replaced by other water in the aquifer quickly enough to prevent the well from going dry. The best type of material for an aquifer is a large unlithified or weakly lithified beach sand-type deposit. In New Jersey, the Kirkwood-Cohansey sands form a huge aquifer of relatively unconsolidated beach sand. The famous Ogallala Aquifer, which supplies water to South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, and Texas, is the largest single aquifer in the United States and is composed of weakly consolidated river sand and gravel.

In each of these cases, water is carried in the open spaces between mineral or sediment grains, which provide the primary porosity of the material. Infiltrating water travels in a circuitous route around individual sediment grains as it settles deeper into the earth under the force of gravity. The water reacts chemically with the surface of the grains, dissolving some chemical compounds while precipitating others. In this way, pollutants and other ions can be removed from the water, and other compounds can



be added. “Hard” water is produced by chemical species that capture ions, primarily calcium carbonate (calcite or lime). The finer the grains in the aquifer sediment, the more surface area the water makes contact with and the more chemical exchange and purification takes place. The infiltrating water must squeeze between grains that are in contact. The necks formed by these grain contacts are so narrow that not all components of the infiltrating groundwater can pass through. In particular, bacteria, viruses, and solids are filtered out in these passages. It is by these filtering processes that groundwater is purified into potable water for household use.

In contrast to an aquifer, an aquiclude has very little to no permeability. As such, groundwater will not be able to flow through it, regardless of its porosity, which can be quite variable, and therefore it is not used for water production. Typically, aquicludes are composed of shale or dense clay, although they can be of other rock and sediment types as well. Under the right orientation relative to gravity, aquicludes may bind and thus seal aquifers, allowing the water pressure to increase in them as in a garden hose. This geometry is called an artesian system. If

an aquiclude has minor permeability and flows small amounts of water, it is called an aquitard, which is like a leaky aquiclude. These units may produce water for small applications but cannot be major water producers.

There are typically two aquifers in most areas. The unconfined or shallow aquifer is a water-bearing layer that extends to the ground surface. It typically is composed of soil and contains the water table for the area if rainfall is plentiful. This was the layer in which wells were historically dug by hand and water was retrieved by means of a hand pump or bucket. The problem is that most surface and subsurface spills of any number of noxious liquids ranging from leaking septic and oil tanks to herbicides and pesticides will quickly filter down into the water table, rendering this aquifer polluted and the water not potable. Few people utilize the shallow aquifer in populated areas. The exception to this occurs in coastal areas, where deeper waters are saline. It is this dependence on water from the shallow aquifer or surface water that interacts with the shallow aquifer, which is invariably of poor quality, that causes many of these areas to be cancer alleys.



**Fern Hammock Springs in Ocala National Forest, central Florida—an artesian spring of the Floridian Aquifer** © Raymond Gehman/CORBIS)



Deeper aquifers are typically confined between nonaquifer layers and require drilling to access them. Water must travel a long distance filtering through many rock and soil types to reach this aquifer from the surface. It makes contact with many mineral surfaces, where contaminants can be removed. The water also filters through tightly packed grains and fragments, which remove the bacteria and viruses. Water in confined aquifers is typically clean and provides abundant community and private well water. Confined aquifers, however, are not safe from pollution. Some pollutants are denser than water (DNAPLs dense nonaqueous phase liquids) and filter more quickly than water to these deeper aquifers. Most of these aquifers get the majority of their water from some distant location where the aquifer unit breaches the surface. These areas are called aquifer recharge zones. Any surface pollutants there will slowly contaminate the aquifer and eventually make it unusable, and a still deeper aquifer must be found.

Deeper aquifers may not have the same permeability as shallow aquifers because the rocks are subject to cementation by ion-bearing fluids and compaction by overburden. Deeper fluids may be more saline in some areas and tend to have higher radon levels than shallow waters.

### FRACTURED ROCK AQUIFERS

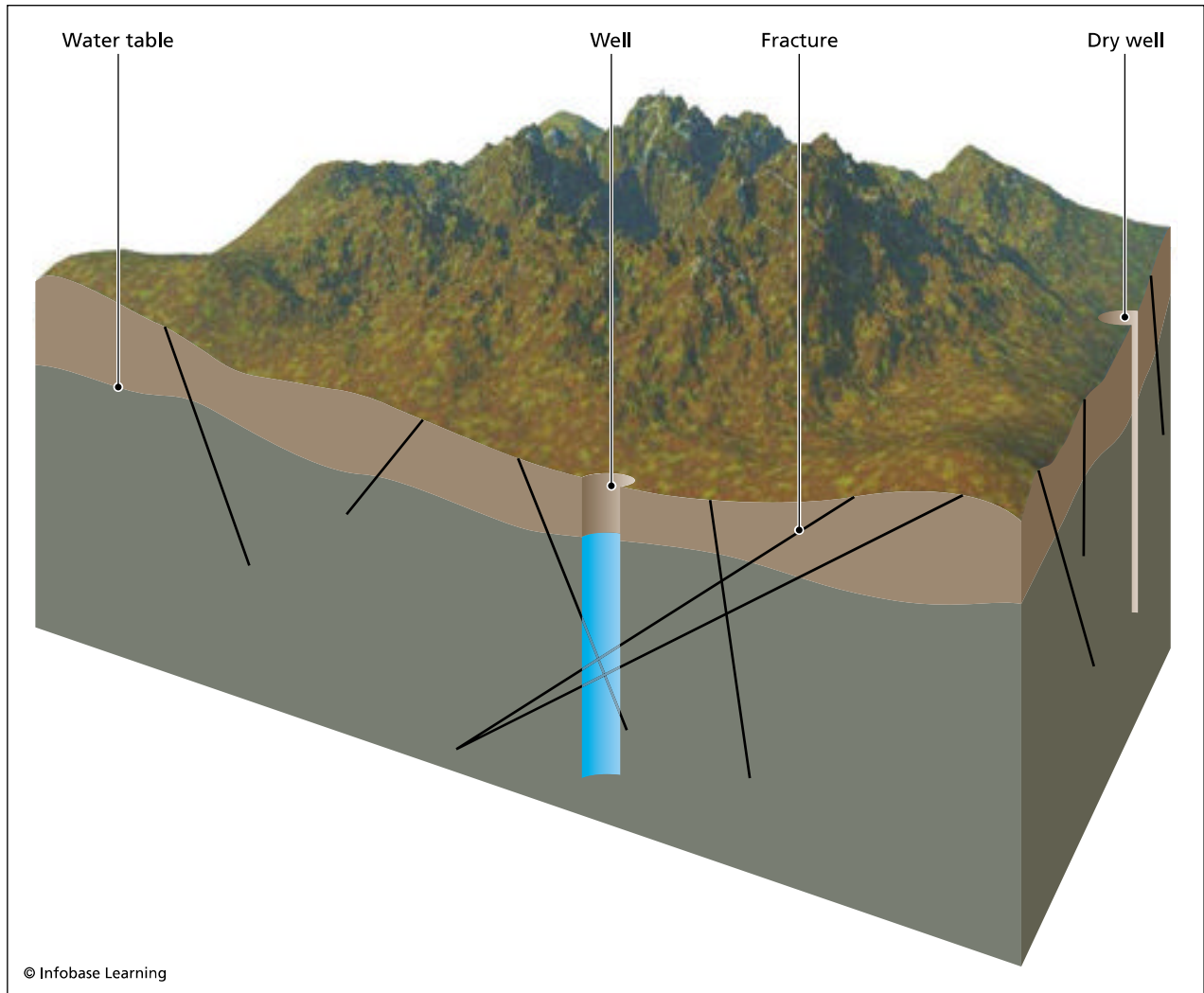
Crystalline metamorphic and igneous rocks do not have primary porosity and permeability. The mineral grains are knit too tightly together and leave no room for pore space. These rocks can form fractured rock aquifers if they contain sufficient secondary fractures. The fractures make up an interlocking network to transmit water but are independent of rock type and therefore difficult to predict. If the fractures are relatively planar and parallel or subparallel, they form joints. Fractures and joints can be tens of yards long and have apertures up to 0.25 inch (5 mm) or more. In terms of water flow, these joints and fractures act more as pipes than typical porous aquifers. Groundwater infiltrating joints and fractures make minimal contact with the rocks, reducing the chemical reactions and thus the purification. The apertures of the joints and fractures are so large that microorganisms and particulate are not removed. They effectively function as water pipes do in a house. For these reasons, groundwater in crystalline rocks tends to be of lower quality and very sensitive to human activity, both on the surface and underground. If the density of the joints and fractures is high, then drilling for water in crystalline rocks yields similar results to drilling in sediments and sedimentary rocks with potentially even

higher yields. Zones of very high fracture density are fracture zones or fracture trends. If the joint and fracture density is low, the odds of intersecting them with a drilled water well decrease significantly, and wells may have to be drilled very deep before they encounter producible water. The inconsistent nature of joints and fractures means that one house may be able to produce water from a shallow well and the next-door neighbors might have to drill deep wells for their water.

Any area underlain by crystalline rock will produce water from fractured rock aquifers or not at all. Many areas of the United States are underlain by crystalline rock. Along the East Coast, the entire Piedmont Province except the Mesozoic basins (Hartford, Newark, Gettysburg, Taylorsville, Richmond, Dan River, etc.) and the entire Green Mountains, Highlands Province, and Blue Ridge Mountains are crystalline rocks and rely on fractured rock aquifers. This means that the cities of Boston, New York, Philadelphia, Baltimore, Washington, D.C., and Atlanta, among others, are all underlain by crystalline rock and fractured rock aquifers. The Northeast also has glacial deposits over the crystalline rock, forming a complex double aquifer system in many cases. Crystalline rocks are also present where the Canadian shield juts into the United States across northern Michigan, Wisconsin, and Minnesota, but they have glacial cover there as well. From the Rocky Mountain front westward, there is a complex interlayering and interfingering of crystalline rocks and sediments. In the Basin and Range Province, much of the range area is crystalline, whereas much of the basin area is sediment. Other very large crystalline rock areas include the Sierra Nevada of California, the Columbia River and Snake River plateau of Washington, the Colorado plateau, the Llano uplift of Texas, the Arbuckle Mountains of Oklahoma, and the Adirondack Mountains of New York.

### KARST AQUIFERS

Limestone erodes to form karst aquifers, geologic formations that yield usable quantities of water. Acidic surface and groundwater infiltrates fractures in the limestone and dissolves the rock around it. With time, cave systems form and transmit groundwater in huge underground rivers. These caves act as larger pipes than fractured rock reservoirs and as such are less effective at purifying water. Virtually all surface water quickly drains into the caves, so rivers are few and small. In areas where the water table is shallow, sinkholes on the surface may appear as small circular ponds and lakes. The surface of these lakes is the water table.



**Block diagram showing how fracture systems produce water in wells**

Karst aquifers are the most environmentally sensitive type of aquifer. Sinkholes have opened up under railroad tracks, swallowing entire freight trains, and, in the early 1980s, a section of Interstate Route 10 in Florida collapsed into a sinkhole at night, and several cars plunged in before the state police closed the road. There is even a story from Egypt that some chickens fell into a well in a karst aquifer only to climb out of another well about a mile away. Not only can karst aquifers transport cars and chickens, they can just as efficiently transport pollutants in far greater quantities than any other groundwater system. In one case, a whole football field-sized industrial waste lagoon disappeared overnight into a sinkhole along the Delaware River, New Jersey, liner and all. With examples like these, it is readily apparent why it is so important that landfills, waste storage facilities, and chemical holding tanks, among others, not be located in karst regions.

Karst systems can be anywhere that there is limestone, but they are far more prevalent in areas of adequate rainfall or extensive groundwater systems. Probably the most famous karst aquifer is the Floridan Aquifer of Florida, Georgia, and Alabama. It underlies virtually the entire state of Florida and is the site of an immense struggle between the agricultural and industrial growth and those who want to preserve the quality of their drinking water. Karst aquifers cover a huge area of the eastern central part of the United States from New York through Ohio, Illinois, and Michigan; southward through West Virginia, Kentucky, and Tennessee; and into parts of other states to the south. The Edwards Aquifer of Texas is also a karst aquifer and has the highest recorded flow rates ever measured in the United States. It, too, struggles with pollution and damage to fragile ecosystems.

### PERCHED AQUIFERS

A perched aquifer is one that sits encased in aquiclude at a higher elevation than the main aquifer for an area. Perched aquifers usually require unusual depositional situations and are most common in glacialized terrenes. Kame deposits (a ridge or mound of sand and gravel deposited by melting glacial ice) in glacial lakes consist of sediments with high porosity and permeability encased within the impermeable clays of the lake deposits. Kame deltas at the various levels during shifting of glacial lake levels also produce clay-encased sands and gravels. Even the scraped bowl-shaped depressions in crystalline rocks may later be filled with sediments that are totally cut off from the main groundwater system. Besides glacial processes, progressive erosion may remove an aquifer from above an aquiclude layer but leave part of it in an elevated position.

Perched aquifers tend to contain small amounts of water, which may dry up during droughts or if they are drained by wells. Their small size enables them to be polluted readily. On the other hand, because they are isolated, the pollution cannot easily escape into the main groundwater system. Love Canal, New York, was in actuality an artificial perched aquifer that contained a large quantity of industrial waste. It was contained in glacial clays and would not have been a problem if homes and a school had not been built directly on top of the waste facility.

See also EDWARDS AQUIFER; FLORIDAN AQUIFER; GLACIAL DEPOSITS; KARST; KIRKWOOD-COHANSEY AQUIFER; LOVE CANAL; OGALLALA AQUIFER; WELLS.

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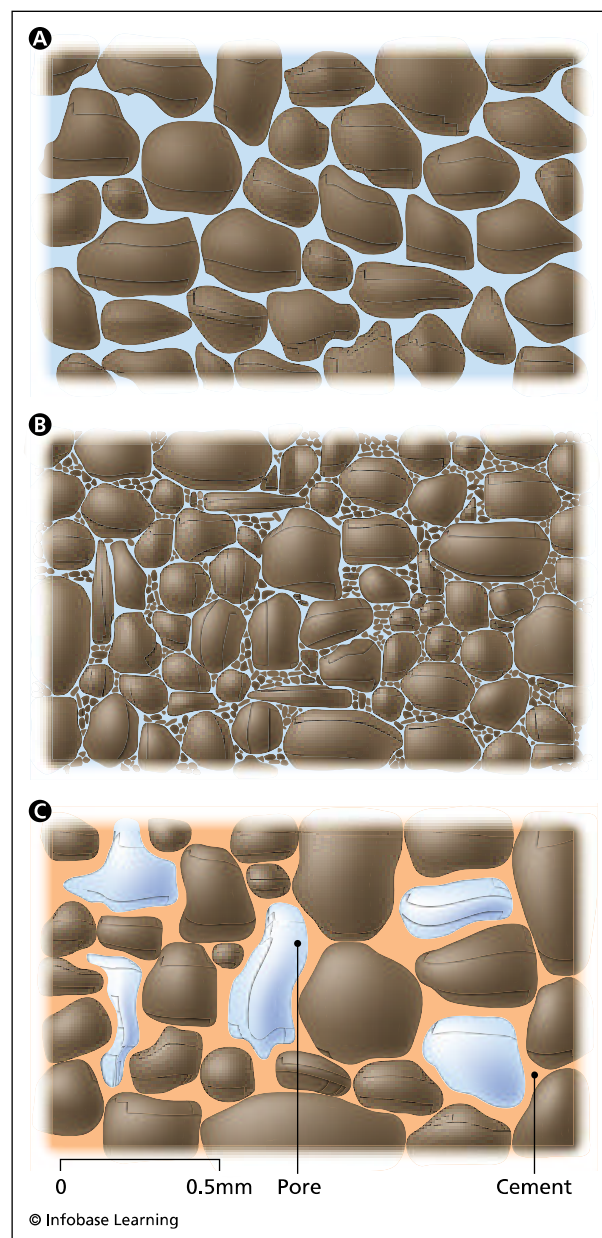
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**Argo Merchant oil spill Georges Bank, New England (December 15, 1976) Water Pollution** A shoal is a relatively shallow area of seafloor that can be a hazard to navigation. If a shoal is hundreds of square miles in area, essentially forming an upland on the seafloor topography (bathymetry),



**Illustrations showing the relationship between textural features and porosity/permeability in sediments. Equigranular rounded grains show good porosity and permeability (A); grain sizes show greatly reduced porosity because the small grains fill the pore spaces (B); mineral cement coating the pores preserves most of the porosity but reduces or eliminates the permeability (C).**

it is called a bank. Several banks are found between Newfoundland, Canada, and southern New England. The series of banks to the north are collectively called the Grand Banks. To the south, off Massachusetts, is Georges Bank, perhaps the most well known of the shoals on the U.S. continental shelf. Georges Bank is a 150-mile- (250-km-) long by 78-mile- (130-km-) wide, roughly circular, submerged plateau that rises more than 390 feet (120 m) above the ocean bottom. It is a remnant of the last ice age and was once connected to the New England mainland. As sea level rose during deglaciation, this low-lying, sandy area first became an isolated coastal island and then was submerged and eventually inundated by the Atlantic Ocean.

Georges Bank is very valuable as a fishery. Driven by ocean water currents originating in Labrador, nutrient-rich seawater rushes southward in a clockwise motion across the bank and combines with warmer water from the Gulf Stream moving northward. Sunlight creates optimal conditions for the growth of phytoplankton (photosynthetic algae) and zooplankton (e.g., foraminifera and krill) in the well-oxygenated waters. These tiny, often microscopic life-forms make up the base of the oceanic food web and offer rich feeding grounds for cod, haddock, yellowtail flounder, and the fish that feed on them. More than 120 species of fish are found in Georges Bank along with numerous types of marine birds, whales, dolphins, and porpoises. Georges Bank has been fished commercially for almost 1,000 years.

### HISTORY OF THE SHIP

The tanker *Argo Merchant* was built in 1953 in Hamburg, Germany. The ship had an operational history plagued with mechanical problems, collisions, groundings, and a near-sinking. Originally christened the *Arcturus*, it was 640 feet (197 m) long, had a beam (width) of 84 feet (26 m), and displaced almost 19,000 tons (17,273 metric tons). With a single steel hull that extended 34 feet (10.5 m) below water, the *Argo Merchant* could travel at 16 knots (29.6 km/h) and carry almost 8 million gallons (32 million L) of oil. Its first 10 years were uneventful, but starting in 1964, the *Argo Merchant*'s machinery and engines began to break down. Over the next 10 years, it was involved in more than a dozen incidents.

In 1967, during a voyage from Japan to the United States, the *Argo Merchant* collided with a Japanese ship, caught fire three times, and had to stop for repairs five times. A journey that only should have taken several weeks lasted more than eight months. This was followed by a mutiny in 1968, the crew

rioting over dangerous working conditions, poor food, and unpaid wages. It went aground off Borneo in 1969, and, in 1976, the boilers failed to operate and the steering mechanism broke down, causing the captain to post warning lights alerting other ships that the *Argo Merchant* was out of control. The ports of Boston and Philadelphia refused to let it dock, and the *Argo Merchant* was even forbidden to pass through the Panama Canal. Sold and renamed several times (*Permina Samudra III* and *Vari*), the ship was purchased in 1973 by a start-up company called Thebes Shipping, Inc., renamed the *Argo Merchant*, and, by 1975, had such a bad reputation that the U.S. Coast Guard tried to prevent it from entering U.S. waters but could not legally enforce such a restriction at that time.

### THE ACCIDENT AND OIL SPILL

In early December 1976, the *Argo Merchant* took on a full load (7.7 million gallons, or 29.2 million L) of No. 6 fuel oil from a refinery at Puerto La Cruz, Venezuela. This fuel oil is a type of liquid petroleum, also called Bunker C, because it often is used as the primary fuel oil for ships and is stored in onboard fuel tanks called bunkers. It is a viscous (thick) oil that flows very slowly at room temperature. In order to be pumped or moved from one tank to another or from a tank to a furnace, No. 6 needs to be heated. Large steam or electric coils that are inside the tank or vessel where the oil is stored usually do this. The cargo of the *Argo Merchant* was destined for the industrial boilers of New England and was needed to keep furnaces fired through the long, cold Massachusetts winter.

As the *Argo Merchant* sailed northward along the east coast of the United States from Venezuela, problems arose. Flying a Liberian flag and under the command of a Greek captain, the *Argo Merchant*'s crew was struggling to keep the ship on course. The gyrocompass was not working, and the radio-direction finder could not be calibrated properly. In addition, neither of the two helmsmen held the necessary ratings to pilot a ship of this class, and the coastal charts that showed harbors and water depths were missing. As the evening of December 15, 1976, came on, the crew tried to navigate using the stars, but the weather closed in, and soon clouds obscured the sky, the seas started running high with 10-foot (3.3-m) waves, and gale force winds drove a blinding snowstorm. At approximately 6:00 p.m., the *Argo Merchant* ran aground on one of the most well-known and charted shoals along the East Coast, the Middle Rip Shoal of Georges Bank, some 20 miles (33 km) southeast of Nantucket Island. At the time





The oil tanker *Argo Merchant* ran aground and later leaked oil on the Georges Banks off the coast of Massachusetts on December 15–21, 1976. (NOAA)

of the grounding, the *Argo Merchant* was almost 25 miles (42 km) off course.

Although the crew worked through the night to refloat the ship and save its cargo, the engine room pumps could not keep pace with the water entering through a tear in the hull. At 7:00 A.M. the next day, the U.S. Coast Guard received a distress call from the *Argo Merchant* and responded almost immediately. After all, the ship ran aground only 50 miles (83 km) from the Coast Guard's main base in Woods Hole, Massachusetts. Arriving with oil containment booms, skimmers, and dispersants, the Coast Guard could only watch in frustration over the next five days as the rough seas and high winds prevented deployment of any oil recovery equipment. Indeed, the crew was lucky to be evacuated by helicopter just before the vessel split in two and sank on December 21, with the full cargo released into the ocean, on the southern edge of Georges Bank.

An oil slick 60 miles (100 km) wide by 100 miles (160 km) long quickly formed. The wreck of the *Argo Merchant*, and the discharge of almost 8 million gallons (32 million L) of Bunker C into the water just off Cape Cod, would become known as

the largest oil spill ever to occur from a marine vessel in the United States until the *Exxon Valdez* disaster in 1989, when 11 million gallons (43 million L) were spilled into Prince William Sound in Alaska.

### ECOLOGICAL EFFECTS AND AFTERMATH

Throughout most of its operational life, the *Argo Merchant* had earned a reputation as a “hard luck” ship, seeming to develop one problem after another and barely making the money needed to keep it afloat. The one piece of luck was that when she ran aground and sank in the stormy waters of the mid-Atlantic, she produced very few short- or long-term ecological effects. The no. 6 oil that the *Argo Merchant* was carrying was constantly heated by steam from the ship's engines. When the ship ran aground and cold ocean water flooded the engines, the oil began to congeal and harden. Although still fluid enough to escape the broken-up ship, the oil tended to sink to the middle of the shallow water column. It did not coat the bottom sediments of the shoal, nor did much of it wash up on the nearby beaches of Nantucket or Martha's Vineyard. Once in the water



column, it began to degrade physically, emulsifying or mixing with ocean water, and biologically under the influence of bacteria and other microorganisms eager to utilize the abundant carbon for their metabolic processes. The stormy weather with strong northwesterly winds pushed much of the oil out to the open sea and away from beaches and fishing grounds. It also was fortunate that the spill took place in mid-December, well into the Massachusetts winter, when biological activity is at very low levels. Most fish and other related aquatic life had moved southward to warmer waters and local fisheries were fairly inactive.

Within a few days of the accident, scientists studying the potential effects of the release noted that petroleum hydrocarbon levels in seawater samples near the wreck were 250 parts per billion (ppb), which are relatively low so near to the source of oil. These concentrations probably decreased further as the rough seas continued to mix and disperse the heavy oil. In 1977, sediment samples collected from shoals where the *Argo Merchant* had run aground did not contain high levels of hydrocarbon contaminants that could be related to the wreck. Today, it is generally thought that the spill had no lasting impact on local ecology.

See also BEACHES; CONTINENTAL SHELF; EXXON VALDEZ OIL SPILL; OIL SPILLS; WATER POLLUTION.

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**arsenic** The classic poison in history, literature, and plays, arsenic can also be an environmental hazard from both natural and anthropogenic sources. Despite arsenic's well-deserved reputation as a poison, more than 60 million Americans have dangerous concentrations of arsenic in their drink-

ing water, for the most part from natural sources. The states with the greatest incidence of arsenic poisoning are Michigan, Wisconsin, Minnesota, North Dakota, and South Dakota. It is even more prevalent in some other countries. It is estimated that in Bangladesh, which has a serious arsenic problem, some 200,000–270,000 people will die of arsenic-induced cancer alone. Other countries that have a high concentration of arsenic in drinking water include Argentina, Australia, Chile, China, Hungary, India, Mexico, Peru, and Thailand. In Bangladesh, China, and India, arsenic in drinking water has caused significant adverse health effects. In the United States, arsenic is considered to be the most dangerous pollutant on the 2007 CERCLA Priority List of the 275 most Hazardous Substances. It has been identified in 784 of the first 1,662 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List), indicating that it is quite widespread.

### SOURCES, USES, AND PRODUCTION

Arsenic is a semimetallic inorganic pollutant primarily from natural sources where the dissolution of rocks such as shale and slate; minerals such as arsenopyrite, realgar, and orpiment; and iron and manganese ores can introduce it into the natural environment. About one-third of atmospheric arsenic is the result of volcanic activity and low-temperature evaporation. Arsenic also can have industrial sources such as wood preservatives, alloying agents, pesticides, mining operations, glass manufacturing, and fossil fuel-burning plants. In 1996, the world leader in arsenic consumption was the United States, which used 24,400 tons (22,000 metric tons). It is estimated that some 70 percent of the world's arsenic production is used for copper chrome arsenate to treat wood (90 percent in the United States), 22 percent is used for agricultural chemicals, and the rest has various uses including paints, dyes, medicine, metal additives, and semiconductors. By 2007, consumption in the United States had decreased to 4,950 tons (4,500 metric tons), mainly as the result of environmental concerns. In 1998, the top industry in the world to deal with arsenic waste was metal mining with 309 million pounds (280 million kg) or 96 percent of the total. Gold mining accounted for 93 percent of the arsenic mine waste. Metal smelting (especially copper) and coal burning add most of the rest.

### ENVIRONMENTAL RELEASE AND CONSEQUENCES

Arsenic can be a point source pollutant from industrial discharge, leaks, or spills or a nonpoint source

pollutant from most natural sources and fallout. It can be found in lakes, rivers, or groundwater systems as the result of washout in rain or snow or through the discharge of industrial wastewater and dumping. Some arsenic sticks to particles in the water and settles to the sediment on the bottom of lakes or rivers, whereas some is carried along by the water. Ultimately, most arsenic ends up in the soil or sediment, where it can be tightly bound. Microbial action and chemical reactions may convert it into a less dangerous form.

An organic form of arsenic is also commonly ingested in low quantities primarily from seafood. This exposure is not considered to be a health threat to humans. Organic arsenic is also used extensively as an additive in poultry and hog feed and ultimately concentrates in animal wastes. It is uncertain whether this source of arsenic in the environment causes health problems directly or whether it can react to form a pollutant. In the past, inorganic arsenic compounds were predominantly used as pesticides, primarily on cotton fields and in orchards, but that use is now prohibited. Nonetheless, it is reported by the EPA that more than 185,636,503 pounds (84,380,229 kg) of arsenic and arsenic compounds were released into the environment by industry.

Arsenic is just as deadly to aquatic life, land animals, and birds as it is to humans. In soil, it has been shown to reduce crop yield, and some plants can take up arsenic. It is very persistent in the environment and is generally insoluble in elemental form. Some compounds, however, are highly soluble, and these can be readily transported from air or soil into the surface water and groundwater systems. Arsenic can bioaccumulate in aquatic and marine animals, but it is almost exclusively in the organic form, which is not nearly as dangerous. Removal of arsenic from water is typically accomplished by using coprecipitation of iron minerals by oxidation and subsequent filtration. Certain microbes may also convert arsenic into less dangerous compounds through bioremediation.

### HEALTH EFFECTS FROM EXPOSURE

Ingestion of a single large dose of the soluble inorganic variety of arsenic as well as arsine gas is acutely toxic to humans. More than 90 percent of arsenic is absorbed in the digestive tract, where it can cause gastrointestinal problems such as nausea, vomiting, abdominal pain, and hemorrhaging. Additional symptoms are renal failure, cardiovascular effects such as low blood pressure and circulatory collapse, and nervous system effects such as headache, muscular weakness, convulsions, and coma

possibly leading to death. These occur within one to 12 hours of ingestion. Even if the person survives, he or she can suffer from bone marrow depression, hemolysis, hepatomegaly, melanosis, polyneuropathy, and encephalopathy. Chronic exposure can result in muscle cramping, diarrhea, anemia and other blood problems, high blood pressure, cardiac arrhythmia, congestive heart failure, irreversible sensory and motor polyneuritis, endocrine problems (diabetes), bile duct enlargement, and immune deficiencies. Arsenic exposure to the skin can also cause dark skin blotches (hyperkeratosis) and warts on the palms, feet, and upper body. In rare instances, it can cause blackfoot disease, which is a severe form of peripheral vascular disease that can lead to gangrene. In pregnancy, arsenic can pass through the placenta and enter the fetus, causing spontaneous abortions, high male-to-female birth ratios, and low birth weights.

Chronic arsenic exposure at the environmental level over a period of 10 years or more has been documented to cause cancer. Arsenic in drinking water has been shown to result in skin and lung cancer, and it is strongly implicated in cancer of the nasal passages, colon, bladder, prostate, and kidneys. Some studies claim that tobacco can contain as much as 6 micrograms of arsenic in a pack of cigarettes, whereas others claim that cigarette smoke simply exacerbates the effect of arsenic on the lungs and promotes cancer.

### REGULATIONS ON HUMAN EXPOSURE

As a result of the severe adverse health effects and widespread distribution, federal agencies have placed regulations on human exposure to arsenic. The EPA revised limits on arsenic in drinking water from 50 to 10 parts per billion (ppb) on February 22, 2002 (the Arsenic Rule). By January 23, 2006, all public water supplies that serve 15 locations and/or 25 residents on a year-round basis were required to meet this criterion. The new standard required corrective action for 3,000 of the roughly 54,000 community water systems, improving the water supplies for more than 13 million people. Private wells in designated "hot spot" geographic regions should also be tested. The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) of 10 micrograms per cubic meter of air for airborne arsenic in various workplaces that use inorganic arsenic over an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set a designation of immediately dangerous to life and health (IDLH) of 5 mg/m<sup>3</sup> of workplace air.

See also INORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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**asbestos** Asbestos is a shortening of the term *asbestiform mineral* and therefore describes the form of a mineral rather than its composition. Any one of a number of naturally occurring minerals can form asbestos through the addition of water to their crystalline structures. Asbestos must have an extreme aspect ratio (a width-to-height ratio of 20–1,000) and be acicular (needlelike) in form. The most common asbestos is *chrysotile*, or *white asbestos*, which is a mineral in the serpentine group (silicates of magnesium, iron, aluminum, nickel, zinc, and manganese). It has a rolled structure, appearing as a minute straw under an electron microscope but as bundled soft friable fibers to the naked eye. It is less stable than the other types of asbestos but still degrades slowly when exposed to weather or in the lungs. *Blue asbestos* is the mineral crocidolite, which is a variety of riebeckite, a member of the amphibole group (hydrous silicate with iron, magnesium, and other elements). It may also occur as bundles of soft friable

fibers or straight, stiffer bladelike fibers. Amphiboles are much more resistant to degradation and can persist for long periods in the lungs. *Brown asbestos* is another type of amphibole, called grunerite, but sold under the trade name Amosite, an acronym of Asbestos Mines of South Africa. Other recognized asbestos minerals include tremolite, actinolite, and anthophyllite, all of which are amphiboles but none of which is common. Other fibrous minerals such as rutile and apatite have been proposed to be classified as asbestos, but they have not been designated as such to date. Asbestos is rated as the 90th worst pollutant on the 2007 CERCLA Priority List of Hazardous Substances, and it has been identified in at least 83 of the first 1,585 U.S. Environmental Protection Agency (EPA)–designated Superfund sites.

#### PROPERTIES, USES, AND PRODUCTION

For millennia, asbestos has had a variety of applications, with its earliest documented use in 2500 B.C.E. in Finland. In ancient times, it was greatly valued as a "miracle mineral" and employed extensively in everything from lamp wicks to fireproof cloth and insulation, as it was incorporated into until very recently. The most common use for chrysotile asbestos in recent times has been in brake linings for cars, pipe insulation, floor and ceiling tiles, plasters and stuccos, fire-proofing, and house shingles. It also has been used extensively in less common items such as fire blankets, clutch plates, gaskets, caulk, sheetrock tape, some types of house insulation, texture coats and "transite" composite panels, siding, and countertops. Amphibole asbestos is typically applied as insulation for ceiling tiles, fire doors, and gaskets and in asbestos cement sheets and pipes and casing for water and electrical conduits. In many cases, the two types are mixed together for common applications. Probably the most notorious use for asbestos was as a coating for ships. In shipyards, millions of tons of finely ground asbestos were sprayed onto the hulls of ships by large numbers of naval shipbuilders, who, for years, worked in large clouds of asbestos.

The majority of minable asbestos deposits occur in serpentinite rock bodies. Serpentinite results from the alteration and low-temperature metamorphism of an ultramafic body (rocks without much silica and high concentrations of iron and magnesium) such as peridotite under proper conditions. Several serpentinites are present in populated areas such as Staten Island in New York City and near Baltimore, Maryland, and may pose threats as asbestiform minerals are released during excavation and road or building construction on or near the rock bodies. The most productive (and earliest) mined serpen-





Royal Air Force trainees wearing asbestos suits walk through petrol fires in England, November 1941. (© Hulton-Deutsch Collection/CORBIS)

tinite in the East is the Thetford area of Quebec, Canada, in 1878. Other sizable asbestos deposits occur in calc-silicate metamorphic rocks. On an international level, the largest producer of asbestos is Russia with more than 1.18 million tons (925,000 metric tons) produced per year (39 percent of total) in 2006. The peak production of asbestos was in 1977, when it reached 2.4 million tons (2.2 million metric tons), but it has decreased steadily in response to the health concerns. The United States ended its domestic production in 2002, and imports have continued to decline from 7,700 tons (7,000 metric tons) in 2002 to 715 tons (ca. 650 metric tons) in 2009.

### ENVIRONMENTAL RELEASE AND CONSEQUENCES

In natural settings, asbestos is not generally a health risk. The fibers tend to be long and bundled with no risk of inhalation. Asbestos, however, is easily disaggregated and, if ground, forms small 3.0–20.0

by 0.01-micron fibers that are easily made airborne and can float as dust for long period. Asbestos is therefore readily inhaled into the lungs. The sharp fibers can become lodged in lung tissue and cause irritation. Even if just moistened, the size and shape of asbestos fibers make them readily adhere to the lungs and very hard to expel. Asbestos fibers in the lungs can cause a variety of diseases. More than 10,495,930 pounds (4,770,877 kg) of asbestos were reported to have been released into the environment from various manufacturing operations in 2005. In most cases, it is a point source pollutant from a specific building, but it is so prevalent, much can be considered a nonpoint source pollutant because the source cannot be identified.

### HEALTH EFFECTS FROM EXPOSURE

It is estimated that some 9,900 people die of asbestos-related diseases per year. The main asbestos disease is asbestosis, which was first identified in naval

shipbuilders. The numerous fibers of asbestos that become lodged in the lungs cause scarring of the lung tissue not by direct irritation, but by acid produced by the lungs to rid themselves of the asbestos. Eventually, the scarring may become severe to the point that the lungs no longer function and the person suffocates. The time frame between exposure to the onset of advanced disease is on the order of 10–20 years. Asbestosis can be caused by any variety of asbestos but is mainly caused by chrysotile. The second main and probably more notorious asbestos disease is the cancer mesothelioma, which primarily affects the mesothelial lining of the lungs as well as the chest cavity, the abdominal cavity, and/or the sac surrounding the heart. There is evidence that at least 50 percent of malignant mesothelioma is related to asbestos exposure; however, the lapse in time between exposure and occurrence is 35–45 years. The survival time for patients with advanced mesothelioma once it is diagnosed is 11 months. Smokers have a much higher rate of mesothelioma, indicating that tobacco works synergistically with asbestos to cause cancer. The current thinking is that mesothelioma is caused by reactive oxygen species in the lungs as the result of exposure to asbestos with the possible participation of the simian virus 40. Mesothelioma is believed to be more commonly caused by exposure to amphibole varieties of asbestos and especially crocidolite. There are also some nonmesothelioma forms of cancer that appear to be related to asbestos either in air or in water. They include cancer of the larynx, pharynx, stomach, and colorectal region.

### REGULATION ON HUMAN EXPOSURE

Asbestos occurs in both air and water, although it is far more dangerous in air. In nature, asbestos exists in long fibers and bundles; it is the grinding of asbestos for industrial uses that converts it into a killer. The Occupational Safety and Health Administration (OSHA) established a long-term industrial air limit of 100,000 fibers per cubic meter of 5 micrometers or greater (roughly 0.1 fiber per cubic centimeter) for eight-hour shifts and 40-hour workweeks. The short-term exposure limit (STEL) is one fiber per cubic centimeter averaged more than 30 minutes. The EPA set a limit of 7 million fibers per liter of drinking water. In school and residential settings, no asbestos in the air is considered the goal of most cleanup or abatement activities, although it is readily recognized that complete removal of asbestos from the environment is unobtainable because of its widespread presence from both natural and anthropogenic sources.

OSHA has established four classes of hazards in asbestos work and activities. Class I is the most hazardous classification and covers the removal of thermal system insulation and sprayed or troweled-on surface materials that contain or are presumed to contain asbestos. Class II is the second most hazardous and covers removal of other types of materials that contain asbestos, including resilient flooring, home siding, and roofing materials. Class III covers repair and maintenance operations in areas where materials are disturbed that are documented or presumed to contain asbestos. Class IV is for custodial activities dealing with waste and debris that contains asbestos. There are certain regulations that must be adhered to for work with asbestos. The work area must be separated (usually using plastic sheets) as regulated areas in which eating, drinking, smoking, chewing gum or tobacco, and application of cosmetics are prohibited. Workers must be fully covered in a protective suit including gloves and goggles and must wear a respirator that is certified for asbestos work. In areas where class I and class II workers are exposed to asbestos levels exceeding the permissible exposure limit (PEL), daily monitoring of workers is required.

### ASBESTOS IN BUILDINGS

After asbestos was recognized as a health threat, efforts were made to remove it from all buildings and dispose of it. The problem is that asbestos has been used in more than 5,000 products and as such is very widespread. On average, homes, schools, and other buildings have 30 to 6,000 fibers per cubic meter, and even outside air in rural areas averages 10 fibers per cubic meter. Near an asbestos factory or mine, the concentration typically exceeds 10,000 fibers per cubic meter. Literally everyone has these ubiquitous and tiny asbestos fibers in his or her lungs; it just depends on the number and type of fibers, the condition of the lungs, heredity, and other factors as to whether health problems will ensue. The process of removing asbestos from a building was found actually to increase the amount of asbestos in the air for up to two years after the remediation is complete by stirring up the tiny fibers. Exposure levels actually increased in many cases. As a result, new legislation allowing encapsulation of asbestos-bearing material has been passed in many areas, and many have questioned the practice of removing it at all.

The dangers of asbestos have been known for many years, and, as a result, many minerals that are structurally or chemically similar to asbestos have also come under scrutiny over time. Talcum



powder has been potentially found to contain asbestos, as the mineral talc is typically associated with serpentine. If water is incorporated into the crystallographic structure of serpentine, asbestiform minerals are created. Houses insulated with vermiculite have also been scrutinized. Vermiculite is a naturally occurring mica mineral that greatly expands into puffed, wormlike pieces with useful thermal insulating capacity. Asbestos minerals are commonly associated with vermiculite, and industrial facilities that process vermiculite into insulation have high air concentrations of asbestos. It is also used as packing material and in garden products. Lime quarries and subsequently lime for lawns have also been found to be potential sources of asbestos. The amphibole tremolite has been found in asbestos form in several lime quarries in metamorphic rocks, and, as a result, several have been shut down.

Asbestos litigation has become the most expensive of all environmental legal cases, with more than 600,000 claimants and 6,000 defendants. This trend will probably continue into at least the next decade as more asbestos workers and handlers begin to develop asbestos-related diseases. It is estimated that the cost of asbestos litigation will eventually reach \$200 billion, even with limits on claims of the many class-action lawsuits.

See also INDOOR AIR POLLUTION; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE; VERMICULITE MOUNTAIN.

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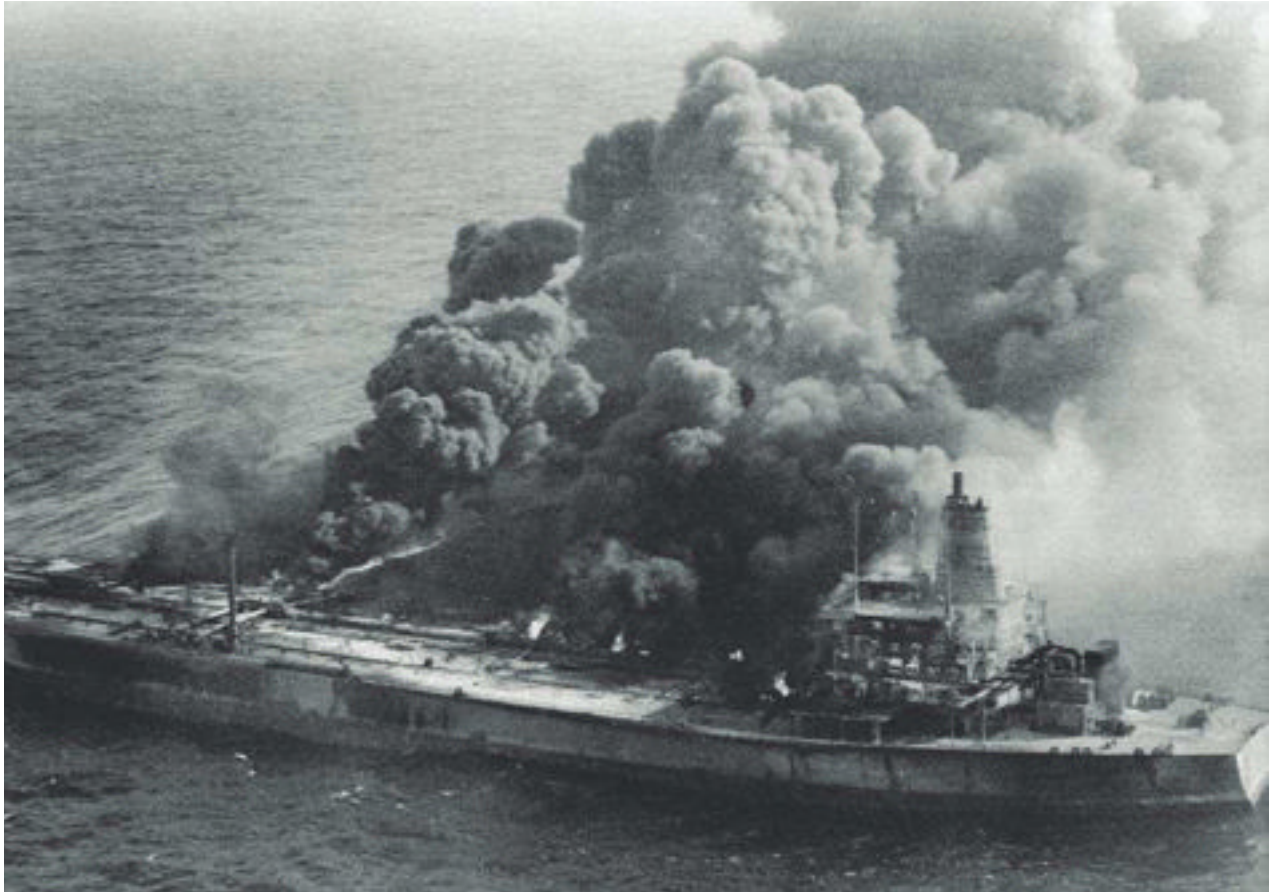
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**Atlantic Empress oil spill Tobago (July 19, 1979) Water Pollution** On July 19, 1979, the weather was severe off the coast of the island of Tobago, in the southern Caribbean Sea. Storms with heavy rain squalls were predicted throughout the night. The two VLCCs (very large crude carriers), "supertankers" used for the transport of liquid fuels weighing more than 182,000 tons (200,000 metric tons), that were in the area that night hardly seemed to notice as they plowed through the dark waters toward their respective destinations. These vessels were enormous, each more than 1,000 feet (454 m) long and less than 12 years old. They were equipped with the most modern navigational equipment available, including radar and radio-direction finders. Both had well-trained crews with good safety records.

Bound for Singapore, the *Aegean Captain* was carrying approximately 1.4 million barrels (59 million gallons, or 269 million L) of Venezuelan refined petroleum from storage tanks in Aruba and Bonaire in the Lesser Antilles. The five-year-old *Atlantic Empress* was carrying 1.9 million barrels (80 million gallons, or 364 million L) of unrefined Saudi Arabian crude oil that had been purchased by Mobil Oil Corporation. The *Aegean Captain* was Greek owned and flew a Liberian "flag of convenience," which is an international registry system sometimes used by shipowners to avoid taxes, labor laws, and more stringent safety requirements than in countries where they may actually be based such as the United States or those in Western Europe. Other countries commonly used as flags of convenience include Panama, Cambodia, and Bolivia, which has no coastline.

## THE ACCIDENT AND OIL SPILL

At approximately 8:00 P.M., these two huge ships collided in a rainstorm about 20 miles (32 km) east of the Tobago coastline. Although the cause of the accident has never been definitively determined, crewmen on deck first raised the alarm when they peered through the fog and rain of a thunderstorm and realized they were only 600 yards (554 m) apart and closing fast. The *Aegean Captain* overtook and smashed into the



The oil tanker *Atlantic Empress* on fire near Trinidad and Tobago, after colliding with another tanker, July 21, 1979 (© UPI/CORBIS)

stern of the *Atlantic Empress*, and both ships burst into flame upon impact, with the *Atlantic Empress* receiving the most damage.

A hole was torn in the *Aegean Captain's* starboard bow and the forward deck erupted into flames, but the crew of 35, assisted by an international team of salvage and firefighting experts, had the conflagration under control and extinguished within 48 hours. One sailor on the *Aegean Captain* lost his life as a result of the collision. The *Aegean Captain* proceeded, partially under its own power, to an anchorage 10 miles (16 km) off the coast of Trinidad for inspection by government officials. The tanker then was towed into port at Curacao, where the cargo was unloaded. During the fires and post-collision maneuvers, the *Aegean Captain* was estimated to have lost approximately 100,000 barrels of oil (about 7 percent), most of which was treated through the use of dispersants during subsequent salvage and towing operations. The *Aegean Captain* was repaired and returned to service within a few months of the collision. The *Atlantic Empress* was not so fortunate.

The collision ripped open a rear fuel compartment, or bunker, on the *Atlantic Empress* and burning oil spilled across the stern decks and into the ocean. Flames leaped more than 100 feet (31 m) into the night air, and a wake of burning oil extended more than 200 yards (185 m) behind the ship. Later, an explosion in one of the ship's center tanks increased the flow of oil into the sea and spread the fires across most of the ship. Eventually the slick from the *Atlantic Empress* covered 10 square miles (25.6 km<sup>2</sup>). Six oceangoing tugboats quickly converged on the scene of the collision and tried to assist the crew of the *Atlantic Empress* in extinguishing the fires and in trying to salvage the ship and her cargo.

Two tugboats managed to attach towlines to the *Atlantic Empress* and drag her farther out to sea, away from more ecologically sensitive shorelines and bird nesting areas. In all, 26 died in the explosion and fire out of a crew of 37 and three passengers. Included in the dead was the radio operator, who remained onboard with the captain to coordinate salvage operations after the rest of the crew and passengers were airlifted from the vessel. Five of

the survivors were hospitalized with severe injuries, including burns. The captain, the last one to leave the vessel, was badly burned after running through a wall of fire to reach rescuers waiting to take him off the ship.

The fires burned for another two weeks until, 15 days after the collision on August 2, 1979, the tanker began to list badly to port and the towropes had to be released. The *Atlantic Empress* sank in several hundred feet of water in the Caribbean Sea, taking with her almost all of the cargo of crude oil.

### ECOLOGICAL AND ECONOMIC IMPACT

The immediate ecological impacts of the collision were relatively minor. Soot from the fires temporarily contaminated drinking water reservoirs in several coastal communities in Tobago. The oil slick from the collision and fires, however, did not reach land, evaporating and dispersing in the sea after being saturated with dispersant from tugs and cleanup vessels. There were no recorded fish or bird kills as a result of this disaster. The *Atlantic Empress* spill, however, occurred at a time when environmental concerns were secondary to those relating to economic impacts, namely, the value of the lost ship and oil. No long-term studies were ever done as to potential ecological consequences of the spill by the government of Tobago, ship's owners, or insurers.

The collision and loss of the *Atlantic Empress* had significant financial implications. Insured by Lloyd's of London, the ship and her cargo of 275,000 tons (250,000 metric tons) of crude oil were valued at \$85 million. This turned out to be the largest financial loss to Lloyd's up to that time, and certainly the largest loss related to a single commercial vessel.

Lloyd's of London is not a business or corporation, but a marketplace where British insurers meet to share the risks and rewards of the commercial insurance coverage they sell collectively. Lloyd's began at a coffee shop owned by Edward Lloyd on the Thames River waterfront. By 1688, businessmen and insurers would meet there to set down the details of the insurance policies for vessel and cargo, signing their names at the bottom of the agreement alongside the amount to which they were committed. This practice of "underwriting" the policy continued even after Lloyd's death, when the process became more formalized and was moved to the Royal Exchange building as the Society of Lloyd's. By the early 1900s, Lloyd's had become the premier insurer in the world, with participants made up of both corporations and individuals.

When a merchant or ship's owner sought insurance, Lloyd's corporate members would form a syndicate designed to insure against specific risks. The members of the syndicate are pledged to reimburse any loss "down to their last collar stud," which is meant to include their own personal fortunes and possessions. In the early days of Lloyd's, it was not uncommon for unskilled underwriters to lose everything when a ship sank or a building burned.

Without affordable insurance, no shipowner or merchant would be willing to accept a cargo for delivery or contract for the movement of oil. The *Atlantic Empress* claim sent shudders through the merchant shipping industry as premiums rose across the board and insurers began to take a much more active role in how tankers were built, maintained, and operated.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS; WATER POLLUTION.

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**atrazine** In a few cases, contaminants can be removed from use and then reinstated. The strong herbicide atrazine had been classified by the U.S. Environmental Protection Agency (EPA) as a Restricted Use Pesticide (RUP) since 1993, but in 2006 most of the restrictions were removed and it was reregistered. Prior to 1993, it was one of the most widely used herbicides in the United States for several years. For example, from 1987 to 1989, it was the most heavily



used herbicide in the country, applied to corn and soybeans in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, Ohio, Texas, and Wisconsin. In 1990, it was applied to more than 64 million acres (26 million ha) of cropland. Trade names and synonyms for atrazine include Aatrex, Actinite PK, Akticon, Argezin, Atrazinax, Atranex, Atrataf, Atred, Candex, Cekuzina-T, Chromozin, Crisatrina, Cyazin, Fenamin, Fenatrol, Gesaprim, Griffex, Hungazin, Inakor, Pitezin, Primatol, Radazin, Simazat, Strazine, Vectal, Weedex A, Wonuk, Zeapos, and Zeazine. Even though atrazine is one of the more widespread contaminants, it occurs in relatively few EPA Superfund sites; thus far, it has been found in only 20 of the first 1,636 sites on the National Priorities List (NLP), where it was analyzed.

### PROPERTIES AND USE

Atrazine is a selective triazine herbicide that has been produced synthetically since 1959. It is an odorless white powder that dissolves in water and is not particularly volatile, reactive, or flammable. It has been used primarily to control the growth of broadleaf and grassy weeds in crops of corn, soybeans, sorghum, sugarcane, pineapple, macadamia orchards, asparagus, and roses, and in grasslands and rangelands, forests, turfgrass sod, conifer restoration plantings, noncropped industrial lands, and fallow lands. The advantages of atrazine are its potency, low cost, fit with soil-saving conservation tillage programs, low risk of crop injury, and versatility in application time—before or after crop emergence. It was for these reasons that it became so popular. Even while it was considered a restricted-use pesticide, the United States used 77 million pounds (35 million kg) of atrazine in 2003. It also has numerous industrial uses including in dyes and explosives.

### ENVIRONMENTAL RELEASE AND FATE

Atrazine is primarily a nonpoint source pollutant discharged as the result of agricultural uses and has only minor point source occurrences at production facilities from releases or spills at storage facilities or during transportation. It is far and away most commonly released to soil, where it is highly persistent. Atrazine breakdown is most commonly the result of microbial activity, which is enhanced by hydrolysis and faster at extremes in pH, especially under alkaline conditions. In dry or cold settings, it may persist for more than one year. It is moderately to highly mobile in soils with low clay or organic content, but it can be adsorbed onto clay-rich soils and colloidal materials. The high mobility means that it is likely to con-

taminate groundwater. Its lack of significant chemical breakdown and slow biodegradation in water make it highly persistent. As a result, atrazine is the second most common pesticide found in wells, both private and public. The states with the most common presence of atrazine in well water are Delaware, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, and New York. It is also common in surface water as the result of runoff from agricultural areas. Atrazine was found in high concentrations in all 146 water samples from locations along the Mississippi, Ohio, and Missouri Rivers and their tributaries in a U.S. Geological Survey study. Part of the 1993 restriction on atrazine was the requirement of a buffer zone between the application area and surface waters as a result of these occurrences. Even though evaporation of atrazine from surface water and soil is insignificant, it may still enter the atmosphere through industrial emissions and agricultural spraying. It is removed through reactions with hydroxyl radicals in air produced by photochemical reactions. Reported industrial release of atrazine was 504,187 pounds (229,176 kg) in 2005.

### TOXICITY AND HEALTH EFFECTS

Atrazine is classified as a class III, slightly toxic, substance. In acute exposures, symptoms include abdominal distress, diarrhea, vomiting, eye irritation, mucous membrane irritation, and skin irritation. At high doses, rats exhibit central nervous system effects such as excitation followed by depression and loss of coordination, accompanied by other effects including muscle spasms, labored breathing, prostration, convulsions, and death. Long-term chronic exposure to atrazine resulted in damage to the heart, lungs, liver, kidneys, ovaries, spleen, brain, and endocrine organs of laboratory animals. About 40 percent of the rats subjected to moderate doses of atrazine died within six months, exhibiting respiratory distress and paralysis of the limbs. In one study, atrazine caused an increase in incidence of mammary tumors in rats over a lifetime of exposure, but no other studies found a link to cancer. One group of researchers also reported that even in small doses, atrazine can be an endocrine disruptor, but the results could not be replicated in other laboratories, and the findings are not considered definitive.

### REGULATIONS ON HUMAN EXPOSURE

Certainly, during its history, atrazine has been subject to tremendous scrutiny, and regulations have been changed drastically. The EPA has set a drinking water

limit of three parts per billion (ppb) under the Safe Drinking Water Act. They have also set limits on contents in foods from 0.02 to 15 parts per million (ppm). The Occupational Safety and Health Administration (OSHA) regulates workplace air to a maximum of 5 milligrams of atrazine per cubic meter for an eight-hour-day, 40-hour workweek. It is unlikely that these standards will change during the reregistration.

See also AGRICULTURE AND POLLUTION; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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# B

## **Bangladesh, arsenic in soil and ground-water Bangladesh (1970s–present) *Water Pollution***

The People's Republic of Bangladesh was established in 1972 after a bloody war of independence with Pakistan. Most of its land area is low-lying, 90 percent within 30 feet (9.1 m) of sea level, and wedged between India and Myanmar on the coast of the Bay of Bengal. The deltaic marshes and jungles that characterize much of the land have been created by soil and sediment deposited by the Ganges (Padma), Brahmaputra (Jamuna), and Meghna Rivers and their tributaries as they flow to the Bay of Bengal. Mild winters and hot humid summers dominate the seasonal climate, with June through October monsoons providing essentially all of the rainfall.

Bangladesh has a population of 147 million, making it the seventh most populous country in the world. Further, all these people occupy an area about the size of Wisconsin, making it one of the most densely populated places in the world. The average population density is 2,600 people per square mile (4,186 people per km<sup>2</sup>). For comparison's sake, the United States has a population density of about 80 people per square mile (129 people per km<sup>2</sup>).

Its alluvial soil is very fertile, filled with organic nutrients within transported sediments and irrigated by soaking monsoon rains. For this reason, farming is the principal occupation in Bangladesh and practiced by about two-thirds of the population. The average annual income is only about \$400, and the country is regularly struck by natural calamities such as droughts when the monsoons do not occur and floods when they do. Bangladesh has also been struck by some of the most deadly cyclones in history, including the 1970 cyclone, one of the worst natural disasters of the 20th century. Its lack

of strong political institutions; the mismanagement of its energy resources, particularly natural gas reserves; and a growing population have all contributed to make Bangladesh an undeveloped nation, with about one-third of its people living in poverty. Developed countries, the United Nations, and several nongovernmental organizations have long been involved in trying to improve economic and social conditions in Bangladesh. Outside aid makes up about 2 percent of Bangladesh's gross domestic product, and it is one of the largest recipients of United Nations resources.

### **ADVANCEMENTS IN PUBLIC HEALTH**

One of the first public health issues Bangladesh faced was the availability of clean drinking water. When it achieved independence in the early 1970s, most of the rural population relied on surface water sources (ponds, streams, and small creeks) as primary sources of drinking water. These surface water supplies proved to be susceptible to bacterial contamination by human and animal wastes. Outbreaks of cholera and dysentery killed 250,000 children every year. UNICEF (United Nations Children Fund, formerly United Nations International Children's Emergency Fund) sponsored a program to replace these surface water supplies with safer, more bacterially free groundwater sources. Almost 8 million tube wells were drilled into the shallow aquifer systems that underlie most of the central and southern parts of Bangladesh. A tube well, also called a driven well or drive point well, is one that is installed by pushing or hammering a perforated pipe or tube into the ground until it encounters a water-bearing zone. The well usually is four to six inches (10.2–15.2

cm) in diameter and less than 20 feet (6.1 m) deep. It can be installed manually, without the need for specialized drilling equipment, using a metal tripod, a pulley, and some weights. The perforated tube or pipe, which is made in five- or 10-foot (1.5- or 3.1-m) lengths, has a sharp, hardened tip. The pipe or tube is placed vertically underneath the tripod directly below the drive weights, which are attached by ropes to a pulley. The weights then are repeatedly raised and dropped onto a special metal drive head, and the pipe is driven into the ground. Additional lengths of pipe can be screwed into the top of the pipe as it advances through the ground. With favorable subsurface conditions, tube wells can be driven to a depth of more than 150 feet (45.7 m) below grade.

Once the bottom of the tube is at the correct depth, a small submersible pump is installed to draw the groundwater to the surface. In Bangladesh this pump, similar to pitcher pumps once so commonly seen throughout rural North America, operates on a treadle system. The person drawing the water simply steps onto the pedals and “walks in place” until water flows out of the spigot. Tube pumps and wells typically can be installed almost anywhere and for less than \$100.

These wells had an enormously beneficial impact on Bangladesh’s agricultural and public health systems. Irrigation became more reliable and less dependent on seasonal monsoons, and crop yields began to increase. The social impacts also were significant. With wells closer to their villages and farms, women no longer had to carry water long distances and could spend additional time on other, more important family-related activities. Infant mortality rates from water-borne diseases plummeted. One study estimated that more than 6 million tube wells were installed across the country in the late 1970s and early 1980s. By the late 1990s, more than 90 percent of the population was drinking groundwater provided by tube wells.

### RESULTING WATER QUALITY PROBLEM

Although the tube wells solved one problem, they introduced another. It would have been a wise decision for U.N. or government officials to have conducted widespread testing of groundwater quality before committing the country to using it for public consumption. Such studies would have shown that the Ganges (Padma), Brahmaputra (Jamuna), and Meghna Rivers and their tributaries flowed through the upland areas of Bangladesh and eroded rocks and sediments rich in sulfide and iron minerals. They liberated naturally occurring deposits of arsenic, which are often associated with these elements. The rivers that carried the fertile soil to Bangladesh



**Results of arsenic poisoning (“blackfoot disease”) on a Bangladeshi in Sonargon, Bangladesh, 2003** (Rafiqur Rahman/Reuters/Landov)

also carried in arsenic. Once deposited in deltas and floodplains, arsenic entered the groundwater as part of a reducing dissolution reaction with iron hydroxide, which increased the arsenic’s solubility.

If ingested at elevated concentrations, arsenic can have significant health effects ranging from wart-like skin lesions, called blackfoot disease, to central nervous system damage, cancer, and death. Although the World Health Organization (WHO) set an allowable limit of arsenic in drinking water at 10 parts per billion (ppb) and the U.S. Environmental Protection Agency (EPA) set the allowable maximal contaminant level for arsenic to 10 ppb, the Department of Environment in Bangladesh has established an arsenic limit of 50 ppb for drinking water, five times higher than the WHO’s EPA standards. The Bangladeshi government feels that public health protection needs to be balanced against the economic realities of their developing country, and to establish a more stringent arsenic standard would place an undue financial burden on both public and private water suppliers. Yet even with this elevated allowable limit, almost 20 percent of the groundwater in Bangladesh contains arsenic at concentrations that make it unfit for human consumption. Arsenic levels in excess of 2,700 ppb have been reported, and the government estimates that 20–60 million people are drinking water with arsenic levels greater than 50 ppb.

It is thought that the best treatment for chronic arsenic poisoning (arsenicosis) is a diet high in protein (preferably meat) and vitamins, to aid in the methylation (conversion of arsenic to a nonbioavailable form) of inorganic arsenic. The resulting arsenic metabolites then are excreted in the urine as long as clean, arsenic-free drinking water is consumed. The rural poor of Bangladesh are particularly prone to arsenicosis,

as their drinking water contains elevated levels of arsenic and their diets are low in protein because it is expensive and difficult to obtain and preserve. The United Nations now estimates that up to 20,000 people a year in Bangladesh could die of drinking arsenic-contaminated water, and this figure may be low because of the long latency period for some types of arsenic-related cancers. This rate exceeds death tolls related to the more widely publicized environmental disasters of Chernobyl and Bhopal.

### POSSIBLE SOLUTIONS TO THE PROBLEM

Both the Bangladeshi government and relief agencies are working to develop solutions to the arsenic crisis. One is to redrill tube wells to greater depths to tap arsenic-free groundwater, although this is an expensive and logistically difficult solution to implement. As well depths increase, pedal pumps cannot provide sufficient lift to carry water to the surface, and the new wells will need to be fitted with electric or diesel fuel-driven pumps. Another solution is to teach Bangladeshi women a filtration technique in which contaminated water is passed through a series of three containers or jars, each holding cloth, sand, charcoal, and iron filters. This process removes much of the arsenic from the water. A similar filtering solution that uses alumina ( $\text{Al}_2\text{O}_3$ ) to absorb the arsenic is available. Even easier to implement is a photo-oxidation technique whereby water is placed in a clear plastic or glass jar, mixed with lemon juice, and allowed to sit in the sun for a few hours. Arsenic is drawn from the water as iron oxide precipitate. Once these oxides are allowed to settle or are filtered out, the water is suitable for consumption. Each of these filtering or treatment processes, however, results in an arsenic-rich residue that must be carefully disposed of to prevent soil or surface water contamination.

The presence of naturally occurring arsenic in groundwater is not limited to Bangladesh. Similarly contaminated aquifers have been reported in Taiwan, Chile, Vietnam, and even Switzerland, and the success of Bangladesh in addressing its arsenic-impacted water will have global implications for these and other countries that want to provide safe, reliable drinking water to their populations.

See also AQUIFER; ARSENIC; BHOPAL AIR POLLUTION DISASTER; CHERNOBYL NUCLEAR DISASTER; SAFE DRINKING WATER ACT.

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**barium** Perhaps the most famous outbreak of barium poisoning occurred several times in the Szechuan province of China, where high levels of barium chloride in table salt periodically produced transient paralysis known as Pa-Ping disease. This potent toxin, however, has caused many other environmental and public health problems. Barium and barium compounds can be divided into two types, the safer types, which do not dissolve in water, such as barium metal, barium sulfate, and barium carbonate, and the more dangerous types, which are water soluble, such as barium chloride, barium peroxide, barium nitrate, barium hydroxide, barium sulfide, barium permanganate, barium cyanide, barium chlorate, and barium acetate. Barium and barium compounds have been found in 798 of the first 1,662 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where they have been tested, a very high percentage. They rank number 109 of 275 most dangerous pollutants on the latest CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USES, AND PRODUCTION

The element (metal) barium was discovered in 1774 and first extracted in 1808. It is a naturally occurring inorganic alkaline earth metal that changes from silvery white to silvery yellow if exposed to air. Barium as metal does not occur in nature; rather, it occurs in compounds, primarily barite (barium sulfate) and far lesser amounts of witherite (barium carbonate). These two compounds are used to produce many of the other compounds. They and the other

barium compounds are commonly white powders or crystals. Barium sulfide is phosphorescent when exposed to light.

Imports of barite rose from 1.65 million tons (1.5 million metric tons) in 2002 to 3.0 million tons (2.7 million metric tons) in 2007 primarily from China (90 percent) and India (8 percent). Domestic production of barite increased from 462,000 tons (420,000 metric tons) in 2002 to 594,000 tons (540,000 metric tons) in 2007. Production was largely from three mines in Nevada and a significantly smaller mine in Georgia. Almost 95 percent of the barite in the United States is used to increase the density of well-drilling fluids for the petroleum industry. The rest has been used as a filler, extender, or weighting agent in paints, plastics, and rubber, and in some specific uses including brake and clutch pads for cars and trucks, automobile paint primer for metal protection and gloss, photographic paper, and additions to the cement jackets around pipelines under water. Barite is part of the mold-release compounds in the metal casting industry. Barite significantly blocks X-rays and gamma rays and is used in concrete for radiation shielding around X-ray units in hospitals, nuclear power plants, and nuclear research facilities. Ultrapure barite as liquid is used for contrast in medical X-rays. It is an ingredient in faceplate glass in the cathode-ray tubes of televisions and computer monitors.

Witherite is used in optical glassmaking (45 percent of use), in brick making (25 percent), in barium ferrites (7 percent), and as photographic paper coating (4 percent); 19 percent is employed in other applications such as case-hardened steel and as a rodenticide. Barium chloride is used in pigments, glass, dyes, leather, and chemical manufacture. Barium peroxide is used in bleach, dye, fireworks, chemical manufacture, welding, and tracer bullets. Barium nitrate is used in ceramic glaze, electronics, neon lights, fireworks, tracer bullets, and detonators. Barium cyanide is used in electroplating and metallurgical applications. Barium hydroxide is used in motor and lubricating oils, grease, plastics, papermaking, sealing compounds, pigments and dyes, polyurethane foam, vulcanization, and coating of limestone. Barium chlorate is used in matches, dyes, fireworks, and explosives.

### ENVIRONMENTAL RELEASE AND FATE

Barium and barium compounds occur naturally in igneous and sedimentary rocks and are released into the environment by weathering as nonpoint source pollutants. They are also released as point source pollutants from mine spoils, ore processing facilities, petroleum drilling operations, copper and steel

foundries, chemical manufacturing plants, landfills, and other disposal sites. The relative mobility and persistence of barium in the environment depend upon the compound. Barium metal, sulfate, and carbonate are highly persistent, but compounds such as barium chloride, barium nitrate, barium acetate, and barium hydroxide dissolve easily in water and do not persist. The liberated barium commonly then precipitates out as less toxic compounds, such as barium sulfate or carbonate, depending upon the chemistry of the water. Barium was found in virtually every surface water sample tested (99.4 percent) in a major domestic survey, primarily derived from natural sources. Some marine species can concentrate barium seven to 100 times ambient levels in water, and some marine plants can concentrate it 1,000 times. Barium is relatively immobile in most soils depending upon the chemistry. Dissolved organic compounds can have higher mobility and leach into the groundwater system. In some states, including Illinois, Kentucky, Pennsylvania, and New Mexico, there are communities where the levels of barium are 10 times higher than the EPA drinking water standards. Barium is released into the air through smokestack emissions from industry (metals and chemicals), incineration, and combustion of coal and oil and as windblown dust from natural sources. Most attaches itself to particulate (dust) and settles to the surface, directly as particles of barium or washed out by precipitation.

During the 1987–93 EPA Toxics Release Inventory, about 58 million pounds (26.4 million kg) were released by industry into the environment, about 99 percent of that to land. The states with the highest releases, in order, were Arizona, Utah, Virginia, New Mexico, Illinois, Tennessee, Alabama, Pennsylvania, Texas, and New Jersey, from copper and steel works, industrial organic and inorganic chemicals, car parts, and paper mills.

### HEALTH EFFECTS FROM EXPOSURE

The soluble barium salts and in some cases barium carbonate are highly toxic. Acute oral ingestion of barium salts can affect the central nervous system and cause vomiting, diarrhea, anxiety, decreased heart rate, increased blood pressure, cardiac irregularities, muscle weakness and tremors, numbness and paralysis, and ultimately death of cardiac and respiratory failure with increasing dosage. Fatal dosage for humans is about 0.8 gram (0.03 ounce) in most cases. Long-term chronic exposure by ingestion or inhalation of dust primarily affects the cardiovascular system. Inhalation exposure can produce a benign pneumoconiosis condition called



baritosis, in addition to symptoms common to ingestion exposure such as high blood pressure, decreased body weight, and reproductive damage including increased fetal mortality in laboratory animals.

### REGULATIONS ON HUMAN EXPOSURE

Barium is regulated by federal agencies because of its public health threat. The EPA established a drinking water limit of 2 ppm under the Safe Drinking Water Act. The Occupational Safety and Health Administration (OSHA) has set the permissible exposure limit (PEL) at 0.5 milligram of soluble barium per cubic meter of workplace air and 15 milligrams of barium sulfate dust per cubic meter for an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set their Immediately Dangerous to Life and Health (IDLH) designation at 50 milligrams of barium chloride per cubic meter of workplace air.

*See also* INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SAFE DRINKING WATER ACT; SUPERFUND SITES.

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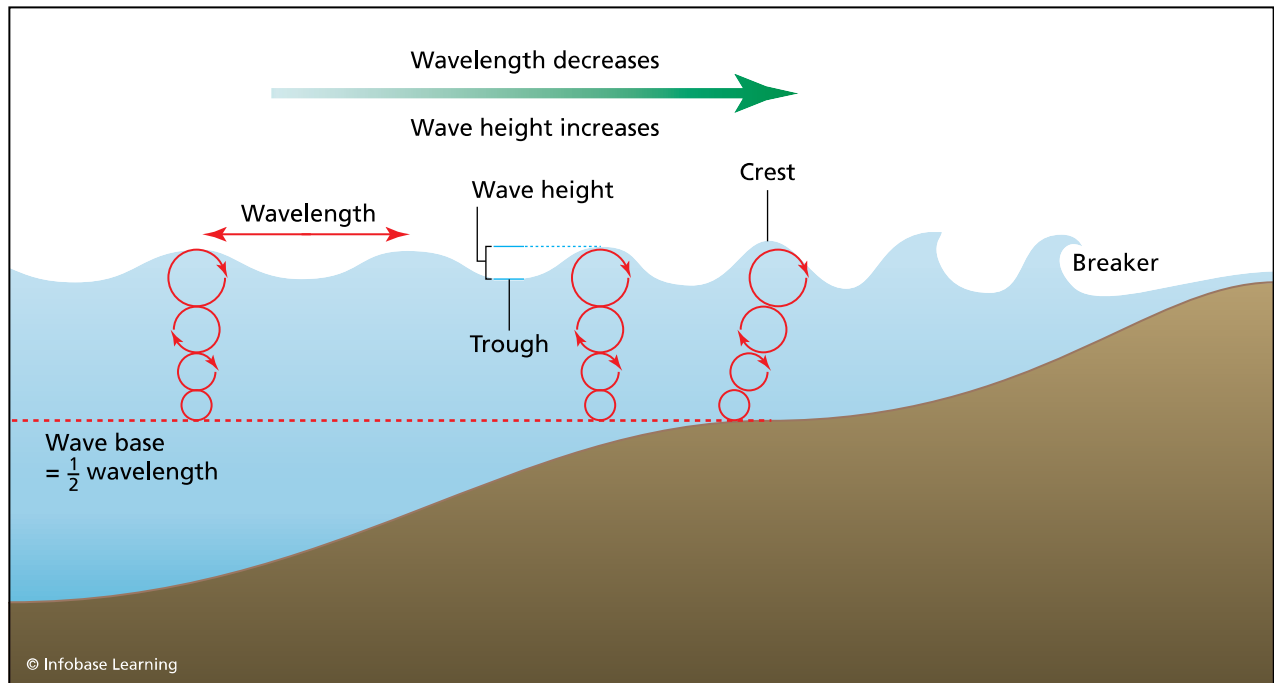
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**beaches** Beaches are long, thin belts of sediments that mantle the continents at their shorelines. The sediments on beaches are predominantly sand, but in areas where there is a rocky coastline, in tectonically active areas, or in areas that have been glaciated in recent geologic history, beaches can have a variety of grain sizes. Sand on beaches is derived primarily from erosion of rocks exposed at the surface on the continental interior and carried to the shoreline by rivers and streams. There waves spread the sand along the coast. In far northern areas and in Antarctica, beach sediment is predominantly glacial in origin, although wave action on rocky shorelines is producing increasing amounts of water-eroded beach sediment in recent years. In areas north of New York City on the East Coast, much of the beach sediment was introduced during the last ice age. In modern times, with the damming of many rivers in populated areas, sediment cannot reach the mouth of the river and is sequestered in the bottoms of reservoirs, causing many beaches to become sand starved, spurring costly replenishment programs to be initiated to save them.

The long trip from the continental interior to the beach wears down the sediment and results in the alteration of unstable rock and mineral fragments into clay. The result is that primarily quartz sand and clay arrive at the river mouth. The clay is swept out to sea, and the quartz sand is transported onto the beach. In tropical areas with good reef development, sands may be composed primarily of calcite from pulverized coral and seashells. As waves and storms attack the reef, pieces of shell and coral break off and are mixed with the sand being pushed shoreward. Even quartz sand is coated with calcite in many areas, demonstrating the close interaction between biological (reef growth) and nonbiological beach forming processes. Where a rugged terrain reaches the coast, sands may be composed of any number of unstable mineral and rock fragments. In Hawaii, beaches are commonly black and composed of sand made of volcanic rock fragments. There was even a green beach composed of olivine (peridot), but it was covered by a recent lava flow. Such beaches are typically small and short-lived, as the unstable rock fragments composing them are readily altered to clay and other minerals.

### WAVES

The shape and dynamic processes on beaches are largely controlled by wave action. Waves are generated by the friction of winds blowing across the ocean surface. The area of ocean surface across which the winds act is the fetch. The stronger and more persistent the wind, the larger the waves.



**Block diagram showing how waves approach the beach. Water particles move in a retrograde circular path in open water. The deepest level in which water particles move is called the wave base. When the wave base hits the seafloor, it drags on it and the wave tips over and “breaks.”**

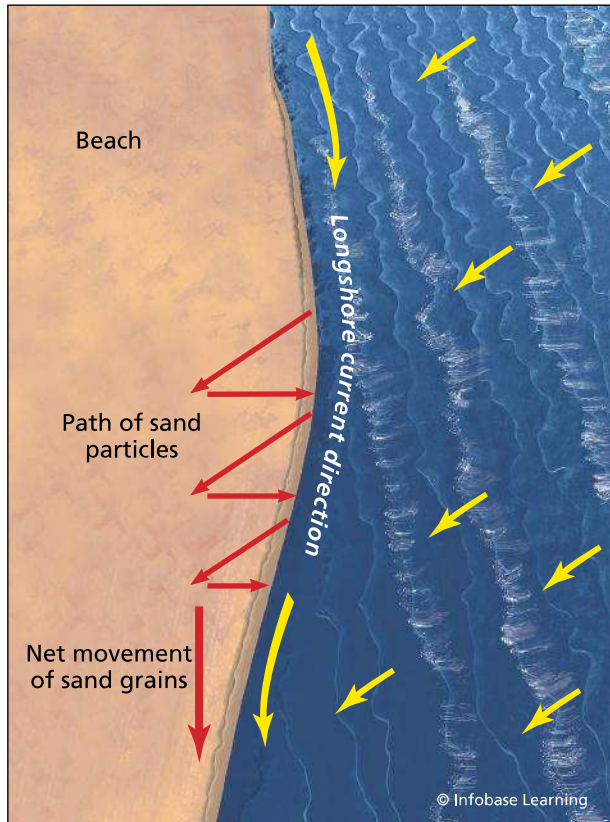
Ocean waves are surface waves that penetrate only the top layer of the water. In open water, they move as symmetric sinusoidal waves with all of the physical aspects including a crest at the top and trough at the bottom, with a measurable wavelength, amplitude, and period. These waves cause individual particles of water to move in orbital (circular) motions that are retrograde (backward) with respect to the forward motion of the wave. Orbital motions in the water occur in a vertical stacked configuration so that each orbital motion becomes smaller at increasing depth below the water surface. At a depth of one-half of the wavelength, the wave base forms a surface below which no water particle motion takes place.

As waves approach a beach, the wave base makes contact with the seafloor. The drag of the waves on the seafloor causes the waves to tilt, so the orbitals no longer align and are no longer round. The wave becomes asymmetric, leaning over toward the beach. As the water becomes shallower, the waves rise up and fall forward as they enter the breaker zone. Water flows forward quickly in the swash zone (the area of the beach along which waves break) and is driven up the beach face as the crest passes. As the trough passes, water retreats back down the shore face. This continuous passage of crests and troughs creates the back-and-forth motion of water at the

beach. The height of the waves that consequently reach up the beach face depends upon the amount of energy imparted to the water from such factors as winds, tides, seasons, and weather conditions.

Above the shore face is a flat area called the berm, and farther landward are the dunes. The size and shape of the shore profile depend on the weather and season. In winter, waves tend to be much larger and stronger. They remove sand and store it in sandbars offshore. The berm tends to be narrower during these times, and the shore face is much steeper. The gentle summer waves plow the sand back onto the beach, widening the berm and reducing the slope of the shore face.

The angle of approach of the wave crests to the shore determines the migration of sand along the beach. If the wave crests are parallel to the shore, there will be no lateral migration of sand. If the wave approaches the shore at an angle, water is pushed laterally along the shore in a *longshore current*. This current carries sand laterally along the beach in a process called littoral drift. The higher the angle between wave crests and the shoreline, the stronger the longshore current and littoral drift are. Beaches have been called rivers of sand because of their constant movement. If beaches were all straight and free of obstructions, there would be no other operative processes, but this is not the case.



**Block diagram showing waves approaching the beach at an oblique angle. The approach angle forces water laterally along the beach, forming the longshore current. The lateral currents force sediment along the beach in a sawtooth pattern caused by the breaking waves. The lateral sediment movement is called littoral drift.**

Where shorelines have embayments, or spits of land, longshore currents may become complex. When waves approach the shore, they slow as the result of friction with the seafloor. If part of the wave approaches the shore while the rest is still in deeper water, as in the case of a spit or embayment, part of the wave will slow, causing it to bend, or *refract*, as it continues to move. Such a geometry may cause longshore currents to move locally in opposite directions. Where they diverge, the sand may be eroded and removed. Where longshore currents converge, however, there is a buildup of water, which quickly escapes to deep water, forming a dangerous *rip current*. Rip currents can pull swimmers very quickly out to sea, thereby posing a threat of drowning to humans.

Certain types of shoreline features can disrupt the flow of the river of sand, resulting in sand-starved beaches in some areas and sand accumulations in others. Piers, groins, and jetties are structures that

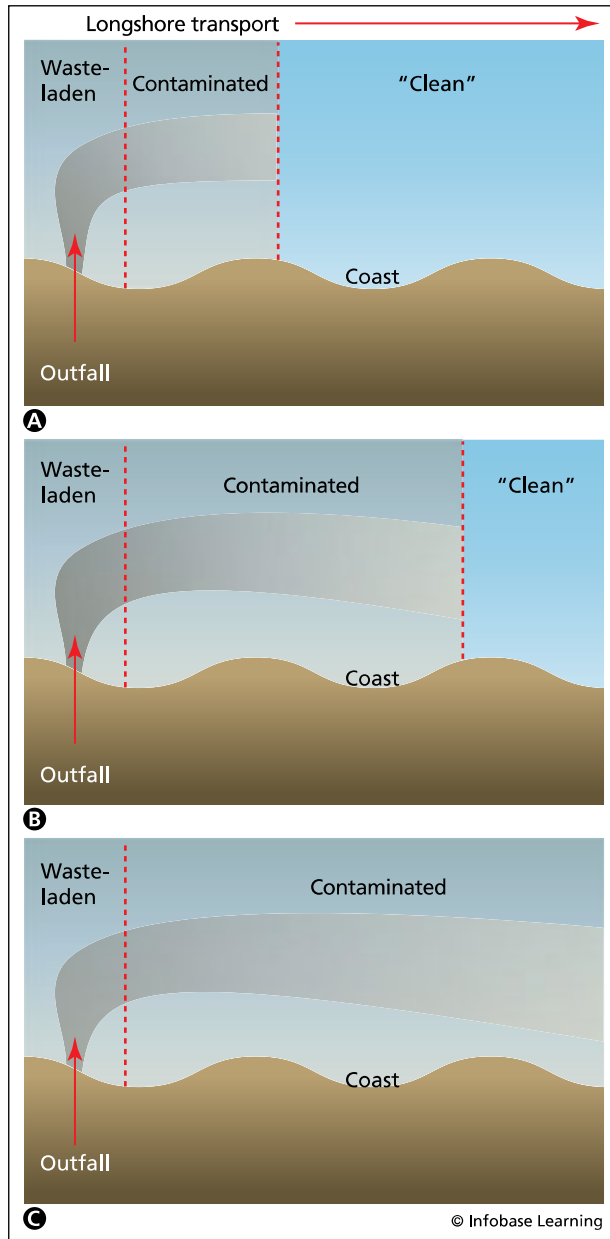
extend directly away from the beach into deeper water that can obstruct the flow of sand. The sand will accumulate on one side of the obstruction, slowly diverting the flow of the longshore current. Eventually, enough sand will be deposited around the structure to allow longshore currents to flow around the obstruction and continue uninterrupted down the coastline. Sand will eventually return to the beach, but the area directly down flow of the obstruction will be sand starved and form an embayment. Breakwaters are obstructions placed just offshore to lessen the power of incoming waves. When the moving water that carries sediment encounters the breakwater in the protected area, it slows, loses energy, and drops its suspended sediment load. The area behind the breakwater fills with sediment, and the sand river simply goes around it, forming a bump in the coastline. It is human practices such as the installation and maintenance of groins, jetties, and breakwaters that cause an otherwise straight and stable beach and coastline to become scalloped and develop sand supply problems. The result may be the need for costly replenishment projects in which sand is moved from deeper water back to the beach or even transported from other areas, thus disrupting the ecosystem of both the supply and replenishment areas.

## BEACHES AND POLLUTION

Pollution of beaches can take many forms. In the United States, there are laws prohibiting the dumping of raw sewage into the ocean, but prior to 1972 and still in much of the rest of the world, this was not the case. Sewage effluence introduces both bacteria and nutrients to grow bacteria that can be harmful to both marine life and humans, causing sickness and disease, both directly to people and animals that enter the water and indirectly to people and animals that consume seafood from infected areas. This is a particular problem with filter feeders and especially shellfish, as the latter are sensitive to bacterial outbreaks. The most common such disease is hepatitis A, which is severe and potentially fatal, but there are many other diseases that can be caused by sewage effluences, as well.

Increased nutrients in coastal seawater from point sources such as sewers or nonpoint sources such as runoff from agricultural areas or even residential areas, coupled with higher temperatures, may also cause dangerous algal blooms. One of the more frequent dangerous algal blooms on the eastern seaboard in recent times is called red tide. In red tide, algae called dinoflagellates multiply in great numbers, turning ocean water a red-brown color. Depending upon the species of algae, mild to fairly

strong toxins, which can cause respiratory distress through airborne transport, even in people who do not enter the water, may be produced. In other cases, fairly strong neurotoxins that can damage or even kill marine mammals both directly and indirectly if they consume affected seafood can be produced.



**A diagram showing how longshore currents transport contaminated water along the coastline, thereby impacting an entire coastal area from a single pollutant spill or drain pipe: Liquid wastes are released offshore (A); continued injection of waste saturates the coastal littoral cell, and the saturated water moves progressively along the shore with the longshore current (B); the result is a strip of nearshore water, parallel to the coast, that is contaminated by liquid waste (C).**

These toxins are also dangerous and potentially fatal to humans if treatment is not administered quickly.

Recently beach pollution has also included washed up solid debris in the form of medical waste. Solid waste from a variety of sources washes onto beaches on a daily basis. Typically, it includes construction wood and general refuse and is largely just an eyesore. In more than one occurrence in 1988, however, beaches had to be closed in New Jersey because used hypodermic needles, sample containers, and gloves, among other medical waste, washed up onto the beaches. This type of waste was also found on Long Island, New York, beaches and several others. In most cases, the source of the waste was never determined, but the incidents underscored the generally poor disposal methods for even dangerous waste.

Oil, fuel, and chemical spills can cause long-term disruption of the operation of a beach. They are by far the most devastating form of beach pollution in terms of impact on the ecosystem and local economy. Oil is the most common and voluminous of the spill types and as such destroys the local ecosystem by overwhelming it. Typically, spills are from grounded tankers, storage and transfer facilities and directly from oil wells. Fuel and most refined chemicals are toxic to marine life, so even small amounts can be devastating. Minor amounts of fuel can be spilled from the tanks of ocean vessels, but more commonly spills result from accidents during transfer of fuel or from leaking storage facilities. Fortunately, fuel evaporates quickly, so the effects tend to be short-lived.

See also COASTAL PLAIN DEPOSITS; EUTROPHICATION; OIL SPILLS; TIDES.

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**Beaufort Dyke Irish Sea, Scotland (1969–present) Water Pollution** Francis Beaufort (1774–1857) was an Irish sailor who had an almost insatiable curiosity about the ocean, its currents, and winds. As



a merchant sailor, he nearly died of starvation at the age of 15 after being shipwrecked because of a faulty chart. Because of this experience, for the rest of his life he dedicated himself to gathering information about the coastlines, tides, and currents of the world's oceans. Many of the tide and shoreline charts he compiled are still in use today, 150 years after his death.

While in the British navy, Beaufort noticed with dismay that most wind observations were subjective. One officer's calm conditions might be another's moderate breeze. In 1805, Beaufort proposed a 0–12 scale based on how the sails of a “man-of-war,” a ship armed with cannon and propelled primarily by sails, were responding to the wind. Zero meant “just sufficient to give steerage”; 12 indicated a wind “that which no canvas could withstand.” By 1830, the Beaufort scale was the standard for ship's log entries in Royal Navy vessels, and, by the 1850s, it began to be adapted for general maritime use. It later would be modified to add categories 13–17 for hurricane conditions and become more quantitative as steam power gained widespread use and shipborne cup anemometers could accurately measure actual wind speed.

Although he did not have much formal education, Sir Francis Beaufort (knighted in 1848) was a strong supporter of numerous scientific and oceanographic expeditions. He served as a council member of the Royal Society, the Royal Observatory, and the Royal Geographic Society. Using these positions to promote worldwide studies of the ocean, he often lobbied to place scientists in key posts within both military and commercial expeditions. For example, one of his more interesting appointments was to recommend a relatively unknown biologist, Charles Darwin, as the naturalist for the HMS *Beagle*'s voyage to the Galapagos Islands.



Improperly discarded munitions pose both a safety and an environmental hazard. (Thomas J. Peterson/Alamy)

## POLLUTION OF THE DYKE

To honor Beaufort and his many scientific and nautical achievements, a 31-mile- (50-km-) long and 2.5-mile- (4 km-) wide submerged trench in the North Channel of the Irish Sea, between Northern Ireland and Scotland, was named Beaufort's Dyke. Dyke is a British term for “ditch” or “channel.” Beaufort's Dyke is just offshore the Scottish port of Cairnryan, where at the end of World War II, the German Atlantic U-boat fleet surrendered, eventually to be towed into the North Channel and sunk. Thousands of troops were based in and around Cairnryan, and the facility continued to play an important role in British military operations after the war. It was at this facility where obsolete and excess munitions were loaded onto barges and dumped into the 984-foot- (300-m-) deep waters of Beaufort's Dyke. The dyke's great depth and closeness to the coast, as well as the fact that it was not a significant fishery, were all important considerations in its selection as a munitions dumping ground.

Ocean dumping was a common and widely practiced way to dispose of surplus munitions. It seemed to be the most safe, efficient, and cost-effective method to get rid of these dangerous and unwanted materials permanently. After both world wars, and until 1976, approximately 2 million tons (1.8 million metric tons) of torpedoes, rockets, bombs, grenades, bullets, and explosives were jettisoned and dumped from barges and ships into Beaufort Dyke. Other materials disposed of in this trench include canisters of the weapon of mass destruction (WMD) nerve agents sarin and tabun, 120,000 tons (109,000 metric tons) of mustard and phosgene gas, cyanide, 330 tons (300 metric tons) of arsenic compounds, anthrax, as well as phosphorus bombs and radioactive waste including laboratory chemicals and luminous paint containing both cesium 137 and radium 226 that were thrown overboard in concrete-filled 40-gallon (182-L) steel drums. Most of the explosives are present at depths greater than 328 feet (100 m), but some of the material was “short-dumped”: The ships under contract to take the munitions out to the trench, whether because of poor weather, faulty navigation, or laziness, never made it and off-loaded their deadly cargo into the shallower seabed, closer to shore.

## THE POLLUTION WASHES BACK

The Irish Sea is an important commercial waterway that links Scotland and England to Ireland. The vast majority of goods and materials between these two important commercial centers move by ship. In addition, the Irish Sea is crisscrossed with pipelines and

telephone, electrical, and other types of cables that provide power, gas, and other services essential to both quality of life and British national defense.

Concerns about the long-term stability and safety of munitions dumped into Beaufort Dyke began to surface in 1966, when British naval authorities started to receive reports of underwater explosions in the vicinity of the disposal trench. Since then, a study of seismograph records by the British Geological Survey documented almost 50 explosions and concluded that it was very likely that many more undetected detonations had taken place.

One serious event took place in 1969 when the crew of the trawler *Aquilon*, who were bottom fishing outside the well-charted 12-mile (19.2-km) exclusion zone surrounding Beaufort Dyke, hauled their nets up and found in them canisters of Eperite, a type of mustard gas or blister agent. This World War I chemical weapon is absorbed through the skin and by inhalation and attacks the body's mucous membranes and respiratory system. It forms large painful blisters and leads to blindness, permanent lung damage, and death. Two of the crew were so severely exposed that their hair and skin began to peel off and their urine burned the skin on their legs and thighs.

In 1995, British Gas, a multinational supplier of natural gas and other types of energy, received permission to construct the Scottish–Northern Ireland Pipeline, a 24-inch- (61-cm-) diameter submerged conduit across the Irish Sea between the Scottish and Irish coasts. Submarine cables and pipelines must be encased in several layers of protective material and surrounded by a tough, flexible metal membrane, especially in an area of high ship traffic or heavy fishing such as the North Channel of the Irish Sea. A barge loaded with spools of cable or pipeline is stationed at the landward starting point and the seaward end of the cable is attached to a marine plow. This plow is towed behind a ship and digs a narrow trench into the seabed at depths of up to eight feet (2.5 m), simultaneously feeding the pipe into the trench. The soft marine sediments quickly resettle into and fill or collapse the trench, effectively protecting the cable from ships' anchors and fishing tackle. Similar protective techniques also can be used such as seafloor jetting or the placement of rocks or concrete mattresses. These and other cable protection methods are most commonly used closer to shorelines and in coastal waters, whereas open or unprotected cable laying is done in deeper ocean water.

British Gas installed its pipeline and meticulously followed all the environmental and routing requirements specified in its permits. One of these restric-

tions was to avoid the Beaufort Dyke and its large cache of discarded and increasingly unstable munitions. Shortly after the pipeline was installed, an estimated 4,500 incendiary devices, mostly phosphorus flares, began washing up on the Irish and Scottish coastlines. Press reports stated that it was not uncommon to see the beaches lit at night by the sparking and burning flares. In two separate incidents, a child and an adult were seriously injured when, out of curiosity, they picked up the hissing and popping metal tubes. Later investigations by the Royal Navy concluded that the pipeline had disturbed a previously uncharted pile of military ordnance that had been "short-dumped" near the Beaufort Dyke. Demolition teams were kept very busy that winter clearing the beaches of these dangerous flares.

Concerned that the presence of the munitions might have a deleterious effect on marine life, the Scottish Office of Agriculture, Environment and Fisheries Department commissioned a survey of the Beaufort Dyke area by its Marine Laboratory. Carefully collecting samples of seabed sediment, fish, and shellfish from within the Beaufort Dyke, the Marine Laboratory concluded that the near-surface seabed sand and silt did not contain detectable concentrations of chemical agents or other munitions. Neither did samples of fish and shellfish meat collected from within the Beaufort Dyke area. The munitions in this ocean disposal trench, therefore, pose more of a hazard to fishermen and beachcombers than to the coastal ecosystem, but careful monitoring of the Beaufort Dyke will be required for many years.

*See also* ARSENIC; BEACHES; CONTINENTAL SHELF; CYANIDE; WAR AND POLLUTION.

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### **Bell Lumber and Pole Company New Brighton, Minnesota (1984–2001) Water and Soil Pollution**

Ever since prehistoric times, wood has played a key role in the survival and development of the human species. Even today, much of the world's commerce revolves around wood and wood products. Wood as a building material, tool, or container has limitations. If used outdoors or in contact with soil, it is susceptible to rot (by water, bacteria, and fungi) and damage by insects. Its appearance also can change, depending upon the environment to which it is exposed. To overcome these limitations, a wide variety of techniques have been developed to maintain the longevity and usefulness of wood and wood products. One method is coating it with pitch, a very viscous, or semisolid, material derived from the sap or resin of plants. Pitch also can be prepared from petroleum, called tar, or bitumen. The ancient Greeks soaked wood used in bridge construction in olive oil to waterproof it, and Romans tarred the hulls of their ships to keep them watertight.

These methods only treated the outside surfaces of the wood, similarly to paints, stains, and sealants, and had to be regularly reapplied or their effectiveness was limited. Today, four primary methods of commercial wood treatment dominate the market: water-based preservatives including chromated copper arsenate (CCA), sodium phenylphenoxide, benzalconium chloride, and guazatin; solvent-based preservatives including pentachlorophenol (PCP), propiconazol, tebuconazol, lindane, permethrin, triazoles, and tributyltin; oil-based preservatives including creosote; and preservatives intended to slow combustion and ammonium salts, borates, phosphates, bromides, and antimony oxides. In all four methods, the preservation process involves impregnating or saturating the wood with chemicals to protect it from biological decay (rot or insect damage) or change in appearance and/or retard combustion.

Treated wood used to be dipped in chemicals that would spill and wash off, but now it is mainly pressure treated. In pressure treatment, wood is placed inside a cylinder that is flooded with preservative. The cylinder then is sealed and all the air removed, creating a vacuum that forces or drives the preservative into the wood. Pressures in the range of 800–1,400 kilopascals (kPa) typically are needed to ensure effective impregnation of the wood. Water-based chromated copper arsenate (CCA) preservative is the most common in the United States and accounts for about 90 percent of the market.

Some studies indicate that CCA can be flushed out of the wood and migrate to nearby soil. Small amounts of CCA are sometimes present on the sur-

face of treated wood. These residues can contaminate food or be transferred to human skin (particularly children's) and may result in unacceptable levels of arsenic exposure. The U.S. Consumer Product Safety Commission recommends that playground equipment be painted or sealed with an oil-based sealer every two years to reduce the potential for exposure to CCA-related compounds. Research on the use of CCA-treated lumber in vegetable gardens has not shown that these chemicals affect the quality or safety of domestic produce.

Of the organic solvent-based preservatives, the most common is pentachlorophenol. A crystalline aromatic compound, PCP is a probable human carcinogenic and toxic organochloride fungicide. It is often contaminated with other toxic organic chemicals such as chlorinated phenols, dioxins, and dibenzofurans, and PCP is a common ingredient in pesticides. Still widely used in industrial settings, PCP helps preserve utility poles, railroad ties, piers, and other lumber destined for commercial applications. The sale and use of PCP were restricted by the U.S. Environmental Protection Agency (EPA) in 1987, and it can only be purchased by specially licensed businesses.

The most common oil-based preservative is creosote, a heavy black-brown liquid produced by condensing vapors from heated carbon-rich sources, such as coal, coal tars, or wood, most commonly beech. As a wood preservative, it is only used in commercial applications and cannot be purchased or applied at a retail or homeowner level. Its registered uses include serving as a fungicide, insecticide, miticide, and sporicide to protect outdoor wood and wood products, primarily utility poles and railroad ties. Approximately 70 percent of the railroad ties in the United States are made with creosote-treated wood, along with 20 percent of all utility poles. It is the most widely used wood preservative in the United States.

### **TREATMENT OPERATIONS**

The Bell Lumber and Pole (BL&P) Company and its next-door neighbor, the MacGillis and Gibbs (M&G) Company, were wood treatment businesses that used chemicals such as creosote and PCP to preserve railroad ties, telephone poles, and landscaping timbers. About 12 miles (19 km) northwest of downtown Saint Paul, both companies began operations in 1918 as storage yards for telephone poles. By the 1920s, they were operating on a combined 24-acre (9.7-ha) parcel, using creosote to treat telephone poles and railroad ties. Creosote usage at both sites ceased around 1960. For the purposes of this

description, both sites will be referred to jointly as M&G.

Initial wood preservation operations at the M&G site consisted of inserting the butt end of a telephone pole (the section of pole that would be in contact with the ground) into a vat or open-topped tank of hot creosote. The pole then would be removed and allowed to air dry. By the late 1940s, M&G began using a mixture of PCP dissolved in a heavy fuel oil and used tanks about 10 times the volume of the original butt tanks so that the entire pole could be submerged in the treatment chemical. In the 1960s, the process changed with the addition of less dense oil as a carrier fluid for the chemicals. This new oil was lighter than water and tended to trap moisture given off by the wood during treatment. The water recovered in this process, whose volume was quite large, along with spent treatment chemicals, was routed to a pond in a low-lying area in the west central portion of the site. By 1970, M&G had ended the use of PCP and switched to CCA.

Land use around M&G was a mix of residential, commercial, and industrial, with the closest homes within a few hundred yards of the site. Several of these homes used groundwater as their source of drinking water. Numerous lakes and streams are within a few miles of the site, and some are used for recreational purposes. Wetlands are present northeast of the site, and these serve as ecological habitats for migratory and native animal and plant species.

By the late 1970s and early 1980s, wood treatment facilities nationwide were coming under scrutiny of the EPA as having the potential to create significant environmental problems. Sloppy handling and waste management procedures, including letting excess chemicals drip from treated lumber directly onto bare soil and letting spillage from treatment tanks run off into local waterways, were causing soil, surface water, and groundwater contamination at sites from New England through the Pacific Northwest.

### INVESTIGATION AND CONTAMINATION

In 1979, M&G reported a spill of 4,000–5,000 gallons (15,142–18,927 L) of CCA solution. This triggered a series of investigations by both EPA and the Minnesota Pollution Control Agency (MPCA) that focused on M&G's waste management practices. MPCA and EPA inspectors began to visit the site regularly to investigate how its spent chemicals and process wastewater were being managed. Many violations were recognized. Some 200 drums containing depleted and used PCP, many in poor condition, were scattered about the site. Also present were unused and abandoned process tanks, some

containing significant quantities of creosote residues. Perhaps the most serious problem was a disposal pit that contained approximately 30,000 cubic yards (22,937 m<sup>3</sup>) of contaminated debris, including treated poles and posts, wood shavings and chips, asphalt, concrete, and processed PCP waste. This pit had been covered with a few feet of soil in an attempt to isolate it from the environment and lessen its visual impact. According to accounts provided by longtime M&G employees, similar fill activities had taken place in low-lying areas along the west central portion of the site. Another approximately 19,000 cubic yards (14,527 m<sup>3</sup>) of metal-contaminated soil was identified in and around the CCA process area.

Alarmed that nearby residents might be exposed to PCP and other treatment chemicals, the EPA and MPCA began a groundwater investigation, and the wells of six nearby homes were sampled. A plume of LNAPL—light nonaqueous phase liquid (oil)—was found to be floating on top of the groundwater underlying the site, and five of the six private wells sampled contained detectable levels of PCP. On the basis of these factors, Bell Lumber & Pole and MacGillis & Gibbs were added to the EPA National Priority List as a Superfund site in 1984.

### REMEDIAL ACTIONS

The EPA and MPCA directed a series of remedial activities designed to stabilize the site and prevent further environmental degradation. The drums were overpacked and removed for disposal at an approved hazardous waste management facility. Obsolete and out-of-service process vessels and piping were cleaned and dismantled, and underlying contaminated soil was excavated and shipped off-site. A special recovery, or “pump-out,” well was installed to remove LNAPL present in the groundwater and a monitoring program begun to continue to check nearby homeowner wells, many of which were now only being used for purposes other than human consumption or contact (e.g., lawn watering or car washing).

Eventually, the EPA and MPCA excavated the disposal pit to a depth of 10 feet (3.1 m) and removed the material to an approved waste management site. This pit was backfilled with less contaminated soil removed from around the site and then covered with a specially designed cap. In this way, the majority of both properties would be remediated with the high-volume, low-risk material effectively contained. The cap will need to be monitored for many years to make sure its integrity is maintained.

Although Bell Lumber and Pole (BL&P) and MacGillis and Gibbs (M&G) were listed as one site, the



reactions by each company to their cleanup obligations were very different. BL&P, a longtime family-owned business, almost immediately entered into a cooperative agreement with the EPA and MPCA to investigate their portion of the site and to participate in funding the \$10-million cleanup. BL&P continues to operate on its portion of this property with a now much more environmentally aware and conscientious attitude. M&G filed for bankruptcy shortly after MPCA and EPA began their investigations and, although it operated for about another 10 years, closed its doors in 1997.

The EPA conducted a five-year review of remedial program effectiveness in 2006 and concluded that cleanup activities completed at the site were protective of human health and the environment, and that potential exposure pathways for waste remaining on site were being controlled. Recently, the city of New Brighton purchased the former M&G property and has redeveloped it for use by a plastics manufacturing company. In addition, two office buildings and a retail store have been built. This formerly contaminated property has now been restored to productive use.

See also ARSENIC; COAL TAR CREOSOTE; PCP; PESTICIDES; SUPERFUND SITES; WELLS.

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**benzene** Benzene is an organic compound from natural and industrial sources and is extensively

used in industry and widely distributed as point source and nonpoint source pollution. It ranks in the top 20 in production of all industrial chemicals in the United States. It is a versatile chemical used for numerous and important industrial applications. It is used as the base for plastics and synthetic fibers such as Styrofoam and other plastics, various resins, cyclohexane for nylon, and other synthetics. It is also used to manufacture certain rubber products, lubricants, dyes, detergents, drugs, and pesticides, and it is present in the BTEX (benzene, toluene, ethylbenzene, xylene) component of oil and gasoline. Although critically important as a commercial manufacturing product, benzene also is regarded as a serious environmental contaminant, ranking sixth on the 2007 CERCLA priority list of 275 most hazardous environmental pollutants. Of the first 1,662 U.S. Environmental Protection Agency (EPA) Superfund sites (National Priorities List), benzene was present in 1,001 of those where it was tested. There are few, if any, pollutants that are more widespread than benzene.

#### PROPERTIES, PRODUCTION, AND USE

Benzene was first discovered in the late 19th century as a by-product of coal tar, but later it was found as a derivative of petroleum, as well. In addition to occurring as a natural component of oil and coal, it is also emitted as part of volcanic eruptions and is a by-product of burning, especially from forest fires and cigarette smoke. Benzene can exist as a liquid, vapor, or gas. It is a clear, colorless liquid that evaporates readily and is highly flammable. It has a strong, pungent, sweetish odor and slightly dissolves in water. It can be smelled at 1.5–4.7 parts per million (ppm) in air and about 2 ppm in water. People can taste benzene in water at 0.5–4.5 ppm. More than 12 billion pounds (5.5 billion kg) of benzene was produced in the United States in 1993, a significant increase over the 9.9 billion pounds (4.5 billion kg) produced in 1984, and demand is increasing.

#### ENVIRONMENTAL RELEASE AND FATE

More than 2 million pounds (909,090 kg) of anthropogenic benzene was released into the environment between 1987 and 1993 according to the EPA Toxics Release Inventory. In 2006, according to the inventory, 5,959,781 pounds (2,708,891 kg) of benzene was disposed of or released to the environment. These accidental releases primarily occurred at oil refineries, with much smaller releases in the metals and chemical industries. The most affected state is Texas, which has six times the volume of accidental

release of Alabama, the second most affected state, followed by Louisiana, Colorado, New Mexico, and Illinois. Benzene can also have numerous nonpoint sources that provide the primary exposure for most Americans including automobile exhaust, power generation from fossil fuels, evaporation from gas stations, and gasoline leakage from underground storage tanks (USTs) at gas stations. Cigarette smoke can also greatly increase benzene concentrations in indoor air. Cigarette smokers, on average, inhale about 1.8 milligrams of benzene per day in smoke, which is about 10 times the total exposure for non-smokers. Inhalation of benzene is by far the most prevalent form of exposure, but ingestion of food, water including bottled water, liquor, and other beverages may also provide significant doses depending upon the source. It is estimated that some 238,000 Americans work in industries where they may be exposed to greatly elevated levels of benzene relative to the general population. Certainly, many of these people work in the industries previously described, but even gas station attendants and firefighters have potentially elevated exposure.

In the natural environment, the persistence of benzenes depends upon a number of conditions. In the atmosphere, it mainly exists in the vapor phase and degrades relatively quickly. In polluted air, it can react rapidly to form other compounds with a removal half-life of four to six hours, whereas in clean air the half-life is more than 13 days. Precipitation can readily remove benzene from air and deposit it into soil and surface water. Benzene in surface water is subject to quick evaporation depending upon wind speed and temperature. It can undergo biodegradation in aerobic surface waters with a calculated half-life of 16 days. In marine environments, degradation was found to have a two-day half-life in the summer and a two-week half-life in the spring, but no degradation was found in the winter. In winter, photodegradation can still remove benzene at the rate of 17 days for the half-life. In soil, benzene evaporates quickly near the surface, but it is highly mobile and tends not to bind to soil. That which is not volatilized typically undergoes significant biodegradation under aerobic conditions but little to no degradation under anaerobic conditions. Rapid infiltration and underground migration of benzene quickly transmit it into the groundwater system, where it poses the greatest environmental threat.

### HEALTH EFFECTS FROM EXPOSURE

Benzene causes significant adverse health effects. Inhalation of benzene typically causes drowsiness, dizziness, headaches, tremors, rapid heartbeat,

confusion, and finally unconsciousness. Even brief exposures to very high levels can be fatal through depression of the central nervous system. Benzene contact with skin results in rashes and lesions, and contact with eyes causes irritation and damage to the cornea. Ingestion of high levels of benzene causes vomiting and irritation of the stomach, followed by the same symptoms as inhalation including coma and death. It operates directly through the liver but also targets the kidneys and brain among other organs. Chronic long-term exposure to low or moderate levels of benzene results in numerous adverse effects including disruption of normal blood production, especially in the bone marrow. Symptoms include the onset of mild to serious anemia, as well as excessive bleeding potentially leading to death. Damage to the central nervous system is also probable including peripheral nerve damage and atypical sleep activity. Chronic exposure to benzene can also damage the immune system leading to increased infections. It is also harmful to reproductive organs and may damage fetuses. Studies show that with prolonged exposure, women had irregular menstrual periods and showed a decrease in the size of their ovaries. Animal studies indicate that exposure of pregnant females to benzene can have harmful effects on developing fetuses including low birth weight, slow bone development, and damage to bone marrow. Chronic exposure to benzene has also been shown to increase significantly the risk of cancer in the form of acute myeloid or erythroblastic leukemias and chronic myeloid and lymphoid leukemias, cancers of blood-forming and lymphatic organs. Animal studies have also found that benzene exposure can cause a variety of cancers in organs including the lungs, skin, mammary glands, ovaries, oral cavity, and the Zymbal gland. The EPA, Department of Health and Human Services, and the International Agency for Cancer Research have classified benzene as a carcinogen.

### REGULATIONS ON HUMAN EXPOSURE

Benzene exposure is regulated by all of the pertinent federal agencies because of its widespread distribution and adverse health effects. With a goal of 0 ppm, the EPA limits the maximal amount of benzene in drinking water at five parts per billion (ppb) under the Safe Drinking Water Act. The surface water goal is also 0 ppm. A maximal level of 200 ppb is recommended for short-term (10 days or less) exposure for children. They further require that the National Response Center must be notified in the event of a benzene spill of more than 10 pounds (4.5 kg). The Occupational Safety and

Health Administration (OSHA) has determined that the maximal allowable exposure to benzene in air is 1 ppm for an eight-hour workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) recommends that workers be fitted with respiration air filters if they are exposed to concentrations exceeding 0.1 ppm for an eight-hour workday. They set their immediately dangerous to life and health (IDLH) designation at 500 ppm in workplace air.

See also EPA; ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SAFE DRINKING WATER ACT; SUPERFUND SITES; TOBACCO SMOKE; UNDERGROUND STORAGE TANK.

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**benzidine** When the federal government became involved in regulation of substances of environmental concern, there were chemicals that went from very common production and use to virtual abandonment over just a few years. Benzidine is one of those chemicals. It is classified as a group A human carcinogen by the U.S. Environmental Protection Agency (EPA), and production was effectively banned in the United States by the Occupational Safety and Health Administration (OSHA) regulations in 1973. By 1976, all large-scale domestic production had ceased, and since then only small amounts of benzidine have

been available for diagnostic testing and research laboratory applications. Benzidine is a synthetic compound that is a nitrogen compound, aromatic amine, and also known as 4,4-bianiline, 4,4-biphenyldiamine, 1,1-biphenyl-4,4-diamine, 4,4-diaminobiphenyl, p-diaminophenyl, among other names, and commercially as Fast Corinth Base B with numerous congeners including o-toluidine and o-dianisidine. It is most commonly present as salts such as benzidine hydrochloride and benzidine sulfate, appearing as a grayish yellow, white, or reddish gray crystalline powder and paste. It is present in only 28 of the first 1,585 EPA-designated Superfund sites (National Priorities List) where it has been tested; yet, it is ranked as number 26 of 275 most dangerous pollutants on the 2007 CERCLA Priority List of Hazardous Substances because of its toxicity.

### PRODUCTION AND USE

Benzidine was invented in 1845 and first produced in a dye (Congo red) in 1884. It was used extensively for more than 100 years and since 1914 primarily in the production of azo dyes, sulfur dyes, fast color salts, naphthols, and various other dyeing compounds. The dyes were primarily used for textiles (25 percent), leather (15 percent), and paper (40 percent). It was also a rubber compounding agent, used in the manufacture of plastic film, and in diagnostic laboratories for the detection of blood, hydrogen cyanide, and sulfate; for the detection of hydrogen peroxide in milk; as a reagent for sugars and a stain for microscopy; and for quantitative determination of nicotine. There are more than 300 colors from benzidine-derived dyes, 18 of which were available in the United States, and of those, 11 were manufactured domestically. The primary dyes were direct black 4,8; direct blue 2,6; direct brown 1A, 2, 6, 31, 59, 74, 95, 154; direct green 1, 6, 8; direct orange 8; direct red 1, 28, 37; direct violet 1, 22; and acid red 85. The peak production for benzidine dyes in the United States was in 1948, when 31 million pounds (14 million kg) was produced. In 1972, the last year before the ban, more than 10 million pounds (9,900 metric tons) of benzidine compounds was produced domestically. In comparison, the domestic production in 1977 and in 1983 was 500 pounds (227.3 kg) each year, though imports totaled 8,900 pounds (4,000 kg) in 1980. Benzidine dye production was still 6.4 million pounds (2.9 million kg) in 1976 but declined to 1.7 million pounds (780,000 kg) by 1978 and continued to decline thereafter. Imports of benzidine dyes were 600,000 pounds (272,000 kg) in 1976, 1.6 million pounds (730,000 kg) in 1978, and 469,000 pounds (213,000 kg) in 1979. In 2003,

there were still nine suppliers in the United States but no manufacturers of benzidine.

### ENVIRONMENTAL RELEASE AND FATE

In the past, benzidine was released to the environment primarily as a point source pollutant from manufacturing facilities as liquids into surface waters or as dust and fumes. Leaks and spills from storage and transport operations also contributed significantly, as did legal and illegal dumping. Today, it enters the environment primarily as leaks from old waste sites. In surface water, benzidine typically sinks and adheres to bottom sludge and sediments, where it tends to remain strongly fixed. Benzidine salts and dyes can dissolve more easily into surface water. In soil, it attaches strongly to clays and organic particles, and, as a result, very little leaches into the groundwater. Degradation in soil is primarily through the activity of microorganisms. In the atmosphere, benzidine exists as very small airborne particles or as vapor that also tends to attach to particles. It can be destroyed by reaction with photochemically produced hydroxyl ions, but it most commonly returns to Earth as fallout or as precipitation washout. Ever since the ban, environmental releases of benzidine have been relatively minor: Releases reported in recent years are 16 pounds (7 kg) in 1993, 250 pounds (113 kg) in 1994, two pounds (1 kg) in 1999, and 532 pounds (241 kg) in 2001. The last reported release of benzidine dyes was in 1989, when 750 pounds (339 kg) of direct black was released.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from exposure to benzidine, the most dire of which is cancer. It is very toxic to humans by acute exposure through ingestion, with health effects including cyanosis, headache, mental confusion, nausea, and vertigo. Skin exposure produces rashes and irritation. Long-term chronic exposure to benzidine appears to cause bladder injury in humans. Laboratory animals suffered numerous adverse health effects from exposure including damage to the liver, kidneys, circulatory system, central nervous system, and brain. Numerous studies have shown that exposure to benzidine causes an increased risk of bladder cancer in humans. Since it has been banned, the rate of bladder cancer has steadily decreased. Benzidine and benzidine dyes have also been implicated in cancers of the liver, kidney, larynx, esophagus, bile duct, gallbladder, stomach, and pancreas, but the connections are not definitive. Studies on laboratory

animals have documented numerous types of cancer from ingestion, inhalation, and injection exposure in mice, rats, hamsters, and dogs. These include cancer of the liver, mammary glands, colon, bladder, and Zymbal gland and injection site tumors.

### REGULATIONS ON HUMAN EXPOSURE

In addition to the ban, human exposure to benzidine is strongly regulated by federal agencies. The EPA limits the amount of benzidine in drinking water to less than one part per trillion (ppt) under the Safe Drinking Water Act, which is essentially 0 because one ppt is well below the detection limits of most analytical equipment. They further require that less than 0.1 part per million (ppm) of benzidine be present in waste taken to disposal sites and that the release of one pound (0.45 kg) or more to the environment must be reported to the National Response Center. The U.S. Food and Drug Administration limits food coloring to less than one part per billion (ppb) of benzidine. OSHA and the National Institute of Occupational Safety and Health (NIOSH) treat benzidine as a carcinogen. NIOSH estimated that 79,200 workers were exposed to benzidine dyes in their 1972–74 National Occupational Hazard Survey, and 10 years later, the 1981–83 National Occupational Exposure Survey estimated that 33,900 workers were exposed. The 1981–83 survey also estimated that 15,554 workers were exposed to benzidine.

*See also* ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SAFE DRINKING WATER ACT; SUPERFUND SITES.

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**beryllium** Beryllium is a naturally occurring group II metallic element and the lightest of the heavy metals. This inorganic pollutant enters the natural environment both through natural processes such as the weathering of rocks and soils and volcanic emissions as well as through industrial production and waste disposal. Beryllium is derived from two economic minerals, bertrandite and beryl, the latter of which also forms the gemstones aquamarine and emerald with impurities of iron and chromium, respectively. Beryllium is used to produce a variety of industrial compounds including beryllium metal, beryllium-copper alloy, beryllium-aluminum alloy, beryllium oxide, beryllium hydroxide, beryllium chloride, beryllium phosphate (meta- and ortho-), beryllium sulfate (and sulfate tetrahydride), beryllium carbonate, beryllium silicate, and zinc beryllium silicate. It is a strategic metal with vital applications in the defense and aerospace industries. Beryllium is listed as a known human carcinogen and is present in 535 of the first 1,613 U.S. Environmental Protection Agency (EPA)-designated Superfund sites (National Priorities List) in which it was tested. It is ranked number 42 of the 275 most dangerous substances to the environment on the 2007 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USES, AND PRODUCTION

Pure beryllium is silver gray to grayish white and metallic. It was discovered in 1798 but not produced commercially until the 1930s and not until the 1940s in the United States. Beryllium oxide was not produced domestically until 1958. The United States is the world's largest producer of beryllium, primarily from the Spor Mountain area of Utah (18,000-ton [16,363-metric ton] reserve) and the Seward Peninsula of Alaska. Traditionally, the other main producers in order are Russia, China, and Kazakhstan, though Mozambique has recently increased production and Brazil has excellent beryl

deposits as well. Production in the United States was 253 tons (230 metric tons) in 1998 and 110 tons (100 metric tons) in 2002 with imports of 45.5 tons (50 metric tons) and 132 tons (120 metric tons), respectively. In 2005 and 2006, production was 121 tons (110 metric tons) and 110 tons (100 metric tons), respectively, with imports of 84.5 tons (93 metric tons) and 63.6 tons (70 metric tons). Pure beryllium is used to produce disk brakes for aircraft, windows for X-ray transmission, aerospace instruments and optics, parts for spacecraft and aircraft, missile components, nuclear weapons, nuclear reactor parts, fuel containers, rocket propellant, navigational systems, high-speed computers, audio components, heat shields, mirrors, and precision instruments. Beryllium alloys, primarily with copper and aluminum, are used in electrical connections and relays, precision instruments, parts for aircraft engines, submarine cable housings and pivots, automotive electronics, telecommunications, computers, home appliances, dental devices, golf clubs, bicycle frames, and many other applications. Beryllium oxide is used for ceramics, electrical insulators, parts of microwave ovens, armor for military vehicles, rocket nozzles, nuclear reactor fuels, components of lasers, automotive ignition systems, and thermocouple tubing; as a catalyst for organic reactions and in high-temperature reaction systems; and, in the past, in fluorescent lamp phosphors among other applications. Beryllium chloride is used as an acid catalyst in organic reactions and in production of beryllium metal. Beryllium fluoride is used in the production of nuclear reactors and glass. Beryllium sulfate is used in ceramics, and beryllium sulfate tetrahydride is used in the processing of beryllium ores. Other beryllium compounds have limited applications.

### ENVIRONMENTAL RELEASE AND FATE

Beryllium is released to the environment, primarily to the atmosphere from factories, incineration, and coal burning; and primarily to water and soils by the natural weathering of rocks. The estimated natural release of beryllium into the atmosphere is 5.5 tons (5 metric tons) per year from windblown dust and 0.22 ton (0.2 metric ton) per year from volcanic particles, whereas human sources include industry at 0.66 ton (0.6 metric ton) per year, metal mining at 0.22 ton (0.2 metric ton) per year, electrical utilities at 3.85 tons (3.5 metric tons) per year, and waste recovery at 15 pounds (6.8 kg) per year. It primarily exists as fine dust particles in air that may remain suspended for up to 10 days before settling to the ground or being washed to the ground

by precipitation. Anthropogenic beryllium in soil is mostly as a nonpoint source pollutant from atmospheric settling and washout by precipitation but also as the result of industrial dumping, mine waste, and incinerator and coal ash disposal as a point source pollutant. Most beryllium does not dissolve in water and remains fixed in the soil, where it may react to form other compounds, but it is unlikely to leach into the groundwater. Wastewater from mining and industrial applications can pollute surface waters, as can air pollution fallout and washout, but beryllium tends to settle quickly to the sediment in most freshwater settings. In the ocean, it can remain suspended for hundreds of years. During the Toxics Release Inventory of 1987–93, more than 340,000 pounds (155,000 kg) was released to land and water by industry. The states with the highest release were Pennsylvania and Ohio with smaller discharges in Michigan, Texas, and Minnesota, primarily through metal smelting and refining operations and petroleum refining.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects caused by beryllium exposure. Acute exposure to it is primarily through inhalation and can result in acute berylliosis, which is characterized by rhinitis, pharyngitis, and tracheobronchitis and may progress to moderate to severe pulmonary symptoms depending upon dosage. Long-term chronic exposure typically leads to chronic berylliosis, which is a systemic disease that is more likely to be fatal than acute berylliosis. It primarily affects the lungs with the development of granulomas that can spread to the skin, bones, liver, kidneys, spleen, lymph nodes, myocardium, muscles, and salivary glands. The EPA first classified beryllium as a group B2 probable human carcinogen but upgraded it to a known human carcinogen in 2002. It has been shown to increase the incidence of lung cancer greatly in humans and possibly breast, bone, and uterine cancer as well. In laboratory rats, mice, and monkeys, beryllium also caused lung cancer, and it caused bone cancer in rabbits.

### REGULATIONS ON HUMAN EXPOSURE

As a result of severe adverse health effects and widespread distribution, federal agencies regulate human exposure to beryllium. The EPA regulates beryllium under the Safe Drinking Water Act to a maximum of four parts per billion (ppb). They further require the reporting to the National Response Center of any spill of beryllium of 10 pounds (4.5 kg) or more and one pound (0.45 kg) or more of beryllium chlo-

ride, beryllium fluoride, and beryllium nitrate. The Occupational Safety and Health Administration (OSHA) set the permissible exposure limit (PEL) at 2 micrograms of beryllium per cubic meter of workplace air for an eight-hour-workday, 40-hour workweek. They have further set an acceptable peak exposure level at 0.025 mg per cubic meter of air for a 30-minute exposure. The National Institute of Occupational Safety and Health (NIOSH) set a recommended exposure limit (REL) of 5 micrograms of beryllium per cubic meter of air on an eight-hour-workday, 40-hour-workweek basis with a designation of immediately dangerous to life and health (IDLH) limit of 4 mcg per cubic meter of air.

*See also* INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SAFE DRINKING WATER ACT; SUPERFUND SITES; VOLCANOES.

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**Bhopal, air pollution disaster** *Bhopal, India December 3, 1984 Air Pollution* The release of methyl isocyanate (MIC) on December 3, 1984, from an agricultural chemicals plant in Bhopal, India, is arguably the world's worst industrial accident. The events leading up to the release have

been reasonably well documented, but its underlying causes are complex and its consequences far-reaching. From an environmental perspective, the deadly cloud of MIC that quietly floated over the city during an early winter temperature inversion did not result in lasting ecosystem damage. The vapors dissipated within a few hours, and no traces of residual MIC from the release could be found in soil, in groundwater, or on plants or vegetables. From a political and economic standpoint, however, Bhopal became a rallying cry for environmentalists around the world and played a major role in redefining governmental oversight and corporate environmental obligations, especially in developing countries.

### BACKGROUND ON THE PLANT

Very stringent precautions must be taken in the manufacture, transport, and processing of MIC ( $C_2H_3NO$ ). Used as one of the main ingredients in carbamate pesticides, it is a highly volatile, clear, colorless, pungent liquid. It reacts violently with water, quickly heating and boiling to produce isocyanic gas. MIC is highly flammable and has a low flash point. At temperatures below 102.4°F (39.1°C), it rapidly evaporates and, because it is heavier than air, tends to follow local topography and move downhill if released.

Exposure to MIC causes multiple adverse health effects. If inhaled at concentrations as low as 0.4 part per million (ppm), MIC can induce coughing, chest pain, shortness of breath, skin damage, and eyes, nose, and throat irritation. At more than 20 ppm, injuries are serious and long lasting, with pulmonary or lung edema, vascular hemorrhage, bronchial pneumonia, and death. At 2 to 4 ppm, MIC acts as a potent tearing agent, whereas at 21 ppm, corneas are burned and permanent blindness occurs.

In the 1960s, India was struggling with grinding poverty and a sluggish economy. The country was having trouble feeding itself and maintaining political stability. Understandably, it was with much excitement that the Indian government announced in 1969 that Union Carbide Corporation would build a new agricultural chemicals plant in Bhopal in central rural Madhya Pradesh. Working in close cooperation with the Indian government, which had a one-third ownership, Union Carbide built the plant to make pesticides and fertilizers for India's farmers, who were just beginning to learn and utilize Western agricultural methods. The plant opened on the outskirts of this small (120-square-mile, or 308-km<sup>2</sup>) densely populated metropolitan area, in an economically depressed section, called Jai Prakash Nagar. It employed around 600 people on three

shifts. Encouraged to go to Bhopal by tax and other economic incentives, Union Carbide was originally hesitant to build the plant, in part, because of concerns over an inexperienced workforce.

Once fully operational by the mid-1970s, the plant began to produce pesticides and fertilizers from ingredients made in the United States. By the late 1970s, workforce training and quality control procedures had begun to allow the plant to manufacture products directly from raw materials. In 1980, a new product line was added, a very effective carbamate pesticide called carbaryl, trade-named Sevin. This pesticide was in wide use in the United States. The manufacture of Sevin required large quantities of MIC, and Union Carbide was reluctant to allow its Indian subsidiary to handle and store this extremely hazardous chemical. The majority of their MIC was manufactured and stored at the main plant in Charleston, West Virginia, under very carefully controlled and monitored procedures. Bowing to pressure from the Indian government, which wanted the additional jobs that expanded plant operations would generate, Union Carbide reluctantly agreed to begin MIC formulation and processing at Bhopal.

A MIC production unit was installed along with three partially buried stainless steel storage tanks, each having a capacity of 15,000 gallons (68,000 L). By the end of 1984, the Bhopal plant was losing money. India's agricultural infrastructure was improving, and the need to use expensive fertilizers and pesticides was no longer so urgent. There also was a growing cultural resistance among farmers that was leading to a rejection of Western pest control and cultivation methods.

### THE LEAK AND RESULTING DISASTER

On December 2, 1984, the Bhopal plant reopened after a weeklong shutdown, and at 3:00 p.m., about 100 workers, still upset about their seven-day unpaid vacation, began their usual eight-hour shift. The plant was struggling financially, and, as a result, some important maintenance had been deferred, including on several faulty valves on the MIC tank system. In addition, key experienced managers and staff had been replaced with cheaper, less well-trained personnel. At 9:30 p.m., a shift supervisor ordered a worker to clean a 23-foot (7-m) section of pipe that filtered crude MIC before it emptied into the storage tanks. The worker did so by disconnecting a section of the pipe and connecting a water hose to it. For the next three hours, water seeped past a faulty valve in the line and started to react with MIC in process tank no. 610.





**Children blinded by Union Carbide pesticide leak, Bhopal, India, December 5, 1984** (AP Images)

At approximately 11:45 p.m., workers noticed their eyes were tearing and that the pressure and temperature in tank 610 had risen to more than five times the normal levels. As the heat and pressure continued to build inside the tank, the operational crew and their supervisor took a tea break. At 12:40 a.m., the smell of MIC became overpowering and, half-blind and nauseous, workers started hastily to evacuate the plant. A relief valve then burst, and vaporized MIC shot out of a vent pipe 130 feet (40 m) into the air.

At this point, a series of events began that later caused government investigators to shake their heads in disbelief and the relatives of victims to weep in anger and frustration. As alarms sounded and MIC was pouring out of the stack, the facility's fire brigade arrived to establish a water curtain around the vent and essentially wash or scrub the MIC out of the atmosphere, but their equipment was designed to spray water only up to 100 feet (31 m), and the top of the MIC discharge was 130 feet (40 m) above the ground. A gas scrubber inside the stack, which should have pumped caustic soda into the vent pipe, was turned on. This would have neutralized the

MIC, but it failed to function properly, and no caustic soda was ever released. It was another piece of equipment disabled by deferred maintenance. Emergency tanks intended to contain MIC in case of a catastrophic failure of plant systems could not be used, as they already were full of MIC, instead of being empty, as required by plant emergency procedures. A flare system, designed to burn off escaping gas, could not be activated because a replacement part had not yet arrived from the United States. Emergency sirens sounded to alert nearby residents of a release, but they were turned off by plant operators, who feared a panic. No calls were made to local officials to warn them of the deadly cloud of gas now making its way toward the center of Bhopal, as the outside telephone lines were out of order. One of the last to leave, the plant manager, scrambled over a six-foot- (1.9-m-) high fence, fell, broke his leg, but still found a way to run for his life, leaving no one in charge at the scene. More than 40 tons (36 metric tons) of MIC would be vaporized and released into the air before the reaction burned itself out.

Outside the gates, MIC, trapped underneath a layer of cool winter air and pushed along by a gentle



breeze, flowed downhill toward the sleeping residents of Bhopal. Many awoke briefly, smelled something funny, rolled over to go back to sleep, and died. Others awoke, vomited, found it almost impossible to breathe, and struggled to get outside. Tens of thousands of people filled the streets, all struggling to get away from the toxic cloud that was enveloping their homes and neighborhoods. Many who were now blind were killed by inadvertently staggering in front of speeding cars or buses carrying people desperate to escape. By morning, hospitals were filled and local officials had stopped trying to count the dead. Thousands of bodies filled the streets. By about 3:00 P.M. the next day, most of the gas cloud had dissipated, and recovery efforts began in earnest.

An estimated 3,500 people were killed outright by the gas release, and between 200,000 and 600,000 were injured, many severely. Some nongovernmental agencies and advocacy groups estimated that about 10 to 15 people continue to die every month since the 1984 release of damaged lungs and gastrointestinal systems. More than 7,000 animals were killed, and the local economy suffered losses up to \$65 million.

### THE AFTERMATH

The Union Carbide plant was shut down and operations terminated by the Indian government. Suing on behalf of more than 500,000 victims, the Indian government settled with Union Carbide in 1989 for \$470 million in damages. It also exempted Union Carbide employees from criminal prosecution. In 1991, however, the Indian judiciary accepted the settlement amount but rejected immunity from further prosecution of Union Carbide employees. Warrants were issued for the arrest of Warren Anderson, the chairman, when he and others failed to appear in India to face criminal charges stemming from the release.

Compensation finally began to be paid to victims and their families in 1993, delayed as a result of legal and political wrangling between Union Carbide and the Indian government. By then, the settlement amount had grown to \$700 million. Relatives of the dead received \$3,200 per fatality and more for multiple deaths in the same family. Those seriously injured received \$3,000 each. People who had minor injuries were paid a few hundred dollars. In August 1999, UCC was acquired by Dow Chemical in an \$11.2-billion merger. The combined organizations became the second largest chemical company in the world. In 2001, Union Carbide ceased to exist as a corporate entity.

The Bhopal tragedy sent shock waves through both the business and government communities.

Companies reevaluated their chemical processing and manufacturing operations and instituted much more stringent safety systems. They also rethought site selection criteria before deciding to open a new plant that managed dangerous materials. Regulatory agencies around the world passed stringent new laws requiring companies to disclose the types and quantities of raw materials they stored and handled and to prove that their plant safety procedures were adequate and were being followed. The people of Bhopal paid a terrible price for the several hundred jobs Union Carbide introduced to their community, but the world truly learned a lesson from this tragedy, and the Bhopal disaster ushered in a new era of corporate responsibility and stewardship, especially in relation to developing countries.

See also PESTICIDES; TEMPERATURE INVERSION.

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### bioaccumulation and biomagnification

In 1948, the Nobel Prize in medicine and chemistry was awarded to a Swiss biochemist, Paul Hermann Muller. Since the early 1930s, Muller had worked on understanding and developing a class of organic chemicals called chlorinated hydrocarbons. In 1939, after systematically synthesizing and testing hundreds of substances, he found that dichlorodiphenyltrichloroethane (DDT) acted as an extremely effective and long-lasting contact insecticide on Colorado beetles, flies, and many other types of insects.

DDT quickly became the pesticide of choice. Inexpensive, safe, very effective, and easy to use, it could be applied directly as a liquid or powder or mixed with oil-based dispersants and sprayed from airplanes, trucks, or hand-held applicators.

DDT helped control the spread of malaria, manage Dutch elm disease, and increase crop productivity, among other benefits. Unfortunately, the extensive and often uncontrolled use of DDT and other chlorinated hydrocarbon-based pesticides exacted a steep environmental price. The main problem with these compounds is that they have the unfortunate tendency to bioaccumulate and biomagnify.

### BIOACCUMULATION

Bioaccumulation is the intake and concentration of a substance in the tissues of a living organism. In itself, bioaccumulation is a normal and important part of the growth and development of all living organisms. In humans, this process allows vitamins A, D, and K; trace minerals; and essential fats and amino acids to be stored in various tissues and organs for later use in metabolic processes. The same mechanisms in the human body that accumulate nutrients and vitamins also work to store synthetic organic chemicals such as DDT.

Bioaccumulation, when combined with DDT's persistence, makes it a deadly environmental contaminant. Once DDT has been applied, it tends to resist such natural destructive processes as photochemical degradation, interactions with other compounds, and biodegradation. It can remain in the environment for a long time without changing. DDT, like other chlorinated hydrocarbon-based pesticides, is a hydrophobic, lipophilic chemical: It is not very soluble in water and tends to move out of solution and into the fat cells of an organism. Water-soluble compounds do not tend to bioaccumulate. Lipophilic substances are not water-soluble and are not easily flushed. They quickly pass through cell membranes and accumulate in fatty tissues. Once DDT is stored in the body's fat, it is not removed, and it does not degrade. As additional DDT-contaminated fat reserves are added, the amount of DDT increases or bioaccumulates, and, when those fat reserves are eventually used, appreciable amounts of DDT are remobilized into the organism.

Bioaccumulation does not occur at the same rate in all species, or even in individuals within the same species. Animals that are big or fatter tend to bioaccumulate at higher levels than short-lived, small, or slender species. An old trout probably has bioaccumulated more DDT than a young bluegill from the same lake. DDT has been detected in human fat and the milk of nursing mothers. DDT also interferes with eggshell production and was responsible for the near-extinction of the bald eagle, California condor, and other birds. Birds exposed to DDT laid eggs with very thin shells that cracked and broke during nesting.

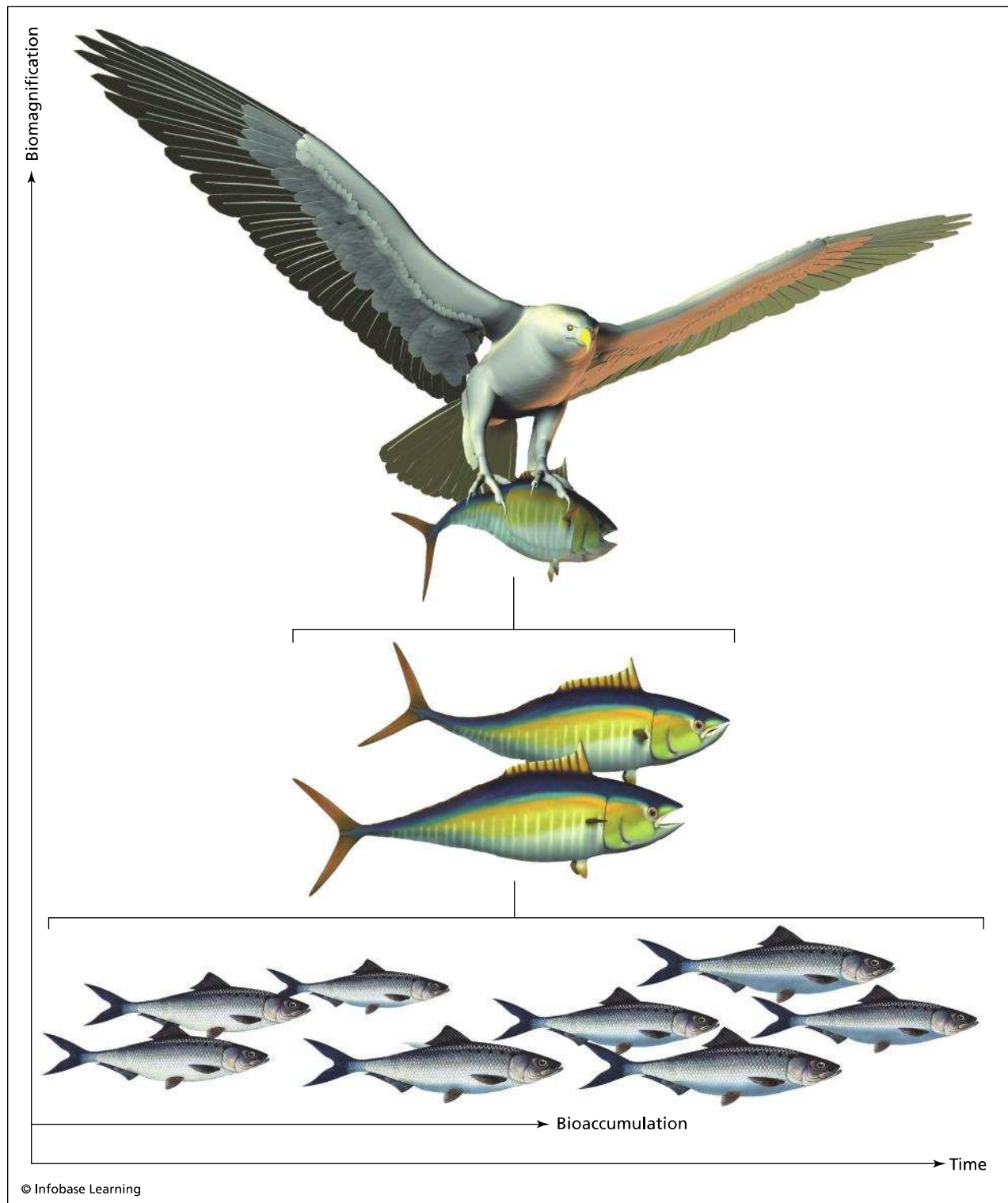
### EFFECTS OF BIOMAGNIFICATION

DDT enters an organism through biological activities that are collectively known as uptake, or exposure mechanisms. These include inhalation of dust and vapor, ingestion of plants or soil contaminated with DDT, or absorption through the skin, feathers, fur, scales, or gills. Once inside an organism, DDT begins to biomagnify. Biomagnification results in the accumulation of a substance in an organism at higher levels than are present in its food supply or surrounding environment. It most commonly occurs as DDT moves up through the trophic levels of a food web. One study of DDT's biomagnification ability found that when concentrations were 10 parts per million (ppm) in the soil, they reached more than 140 ppm in earthworms and more than 400 ppm in robins.

### RECOGNITION AND REGULATION

Although it may seem obvious that pesticides and perhaps other industrial chemicals could bioaccumulate and biomagnify, the possibility was not widely considered during their development and use. That changed in 1962, when *Silent Spring* was published by Rachel Carson. The book carefully and irrefutably documented how DDT and other organochlorinated pesticides entered and worked their way up the food web. Carson's *Silent Spring* is often credited as awakening in the general public an awareness of society's use of chemicals and beginning the modern American environmental movement. Sadly, Carson died of breast cancer two years after *Silent Spring* was published and never saw the wide-reaching effect of her work, not only in the United States but around the world. DDT was banned for sale in the United States in 1972, although it is still manufactured for export to other countries.

DDT is not the only industrial chemical that bioaccumulates and biomagnifies. Like DDT, persistent organic pollutants (POPs) are difficult to degrade and are mobile in the environment. The U.S. Environmental Protection Agency (EPA) recognizes 12 POPs, many of which occur as semivolatile compounds: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, toxaphene, Mirex, hexachlorobenzene (HCB), polychlorinated biphenyl (PCB), dioxin, and furans. Semivolatile POPs can exist as either solids or vapors, depending upon the temperature. Once in the environment, if the temperature is warm enough, POPs such as PCBs or toxaphene evaporate or are carried on dust particles, their distribution being controlled by atmospheric processes. As the temperature cools or the dust settles, the POP can have traveled thousands of miles from



**Illustrated graph of time and bioaccumulation versus biomagnification. Certain chemicals such as DDT and many inorganic elements accumulate in the tissue of fish through ingestion. As fish eat more tainted food over time, more contaminants accumulate in their fatty tissues. This is shown by larger darker areas on the fish toward the right reflecting bioaccumulation. Predators preferentially eat the tainted fish and primarily tissue and organs that contain the contaminants. The higher the predator in the food chain, the more concentrated the contaminant in the body tissues through biomagnification.**

where it was originally released. It is this “grass-hopper effect,” the cycle of evaporation coupled with windblown transport of contaminated dust, settlement, and then remobilization, that results in the worldwide distribution of POPs, with their presence often detected in areas where they have never been used. DDT has been found in arctic ice and PCBs have been reported in the tissues of deep ocean Atlantic cod.

Organochlorinated pesticides and other POPs are being addressed under the EPA’s Persistent Bioaccumulative and Toxic (PBT) chemical program. Action plans have been developed for most of them, and procedures are being implemented to ban their manufacture and use and to track their presence in the environment.

See also ALDRIN/DIELDRIN; CARSON, RACHEL; CHLORDANE; DDT; DIOXIN; ENDRIN; ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; FURAN; HCB; HEPTACHLOR; PCBs; PESTICIDES; TOXAPHENE.

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**bioremediation** In some cases, usually because of the physical difficulty in excavating pollution, undue risk if the material is exposed to the environment, or cost-effectiveness, the best method of degrading or removing pollution from soil or water is to let plants or microorganisms do the work. Although in the environmental industry bioremediation is an advanced technology, it actually takes place all the time in all but the most extreme of climate conditions. Bioremediation is the action of microorganisms, fungi, green plants, or their enzymes to remove pollutants and restore the environment to its natural state. All decay of materials, from moldy bread and spoiled food to compost piles, is accomplished by living organisms. Bioremediation is just directed decay and chemical transformation to remove or neutralize contaminants. Typically, if

plants are the vehicles to remediate the problem, the method is termed phytoremediation. There are also several other subcategory terms and processes in bioremediation, such as biostimulation, bioaugmentation, bioventing, biotransformation, and others that are all part of the bioremediation processes.

Bioremediation is quite a complex science requiring expertise in microbiology, chemistry, and geology for effective use. Typically, a specialist will evaluate the pollution and then choose the most effective microbes to degrade the contaminants. In some cases, the existing microbes in the soil are sufficient to do the job, and the remediation method is called *natural attenuation*. In other cases, conditions must be changed to increase the activity of desired microbes. Air can be pumped into the soil to help aerobic organisms flourish at the expense of anaerobes. Nutrients can also be pumped into soil to help the microorganisms flourish and speed the process. In some cases, the soil is removed and bioremediation is performed *ex situ*. Depending upon the type of pollutant to be removed and the physical situation, different techniques can be employed.

#### ORGANIC POLLUTANTS

It was observed during the first major ocean oil spills in the 1960s that bacteria flourished in the oil and degraded it relatively quickly. These observations are the basis for bioremediation of organic pollutants. In most cases and especially with organic pollutants, bacteria are the best choice for cleanup. Many bacteria under certain conditions of temperature, pH, and soil chemistry are effective as degraders of specific pollutants. Air is commonly pumped into the soil contaminated with organic pollutants to stimulate the microbes so that they will reproduce faster and flourish, thus removing the pollutants more quickly. In some cases, nutrients such as methane, phosphorus, or nitrates are also added. New bacteria may need to be introduced into the soil with or without stimulation methods. When multiple organic pollutants are present, a cocktail containing a mixture of microbial species must be introduced into the area under any number of stimulation techniques to address the pollution problem. The progress of pollutant degradation by the bacteria must be carefully monitored and adjusted as needed.

The bioremediation of organic pollutants involves the bacteria actually dissociating the compounds into other less dangerous compounds, ideally water and carbon dioxide. This is especially useful for organic solvents in situations where pump-and-treat technologies or air stripping are insufficient. The bacteria consume the carbon and other elements as



food. Bioremediation of organic pesticides, however, is not as easy. Many of these pesticides are toxic to bacteria, which cannot function in such a toxic soil environment. In these cases, the pollutant may be very persistent. Dichlorodiphenyltrichloroethane (DDT), for example, can persist in soil for decades because no appropriate microorganisms can survive in it.

### INORGANIC POLLUTANTS

Bioremediation can also be used on inorganic pollutants in some cases, but it is less common. The inorganic pollutants of interest primarily include heavy metals and radioactive elements. Unlike organic pollutants that can be readily changed into common nontoxic substances, inorganic pollutants cannot be degraded. However, the oxidation state of some heavy metals can make them more or less dangerous. For example, hexavalent chromium (+6) is far more dangerous than trivalent chromium (+3). Certain bacteria can change the valence state of heavy metals and allow them to form complexes with other, less dangerous properties. These properties may be that they are less toxic, insoluble, and fixed in the soil or soluble and able to be leached from the soil. There are several problems with bioremediation of metals. In some cases, microbes can actually make the metal more toxic. Mercury is a toxic heavy metal, but it is many times more toxic if it is methylated. Methylated mercury is formed by microbial activity in the natural environment, typically lakes and wetlands. The second problem is that heavy metals are commonly immobile in the soil where they are deposited. Microbial action can complex them into compounds that can be ingested by other organisms. This action allows heavy metal to enter the food chain, where it can do even more damage because heavy metals tend to bioaccumulate and biomagnify.

In some cases, heavy metals and radioactive elements may be removed through phytoremediation. Plants have the ability to partition out certain elements, allowing some into their systems while blocking others. There are certain plants that readily take in heavy metals and radioactive elements. These plants can be grown on tainted soil and actually remove the unwanted elements with time. The problem is what to do with the contaminated plants once they are harvested. Burning them transfers the pollutant into the atmosphere, where it can be inhaled or wind up as fallout and pollute some other area. A good plant for phytoremediation of heavy metals and radioactive elements is tobacco. This is one of the reasons that tobacco smoke is so deadly; it is rich in these inorganic elements.

### GENETIC ENGINEERING

Certain bacteria have bioremediation abilities that others do not. Some bacteria that are excellent at bioremediation may be rare or only able to thrive in conditions that do not characterize common polluted areas. The desirable traits of these inappropriate bacteria may be transferred to more commonly occurring bacteria through genetic engineering. Desirable traits may include enhanced tolerance to adverse conditions or chemicals, ability to reproduce faster, ability to thrive in aerobic or anaerobic conditions as need dictates, ability to dissociate organic compounds, or ability to change the valence state of metals and complex (fix) them into minerals, among others. Genetically enhanced common bacteria can then be introduced into the polluted area to enhance cleanup. Genetic engineering is no easy task and may require huge amounts of laboratory experimentation and sequencing to produce the enhanced bacteria if transfer of the desired trait or characteristic is possible at all. There is also a risk of accidentally introducing unwanted traits into common bacteria that may create other problems. Nonetheless, genetic engineering of plants and organisms to produce quicker and more complete remediation is the wave of the future.

See also CHROMIUM; DDT; MERCURY; OIL SPILLS; PESTICIDES; TOBACCO SMOKE.

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**Blake & Johnson Company Beaufort, South Carolina May 1975 Water and Soil Pollution** In the 1980s, the Blake & Johnson Company (B&J) was one of the largest manufacturers of nails and fastener systems in the United States. As

part of its production process, B&J coated steel, brass, or iron products by passing them through a series of plating tanks that contained various metals such as chromium, zinc, cadmium, and nickel, among others, dissolved in acid. Coating or plating allowed the screws, nails, and other fasteners to be used in a variety of outdoor and corrosion-resistant industrial and commercial applications such as roofing or on boats.

### THE ENVIRONMENTAL PROBLEM

Between 1969 and 1980, B&J discharged approximately 30,000 gallons (120,000 L) per day of plating wastewater into an unlined infiltration lagoon on their 25-acre (4,166-m<sup>2</sup>) property in Beaufort, South Carolina, about 35 miles (56 km) south of Hilton Head. In May 1975, a small section of one of the lagoon's walls failed, and some wastewater was released into an adjacent drainage ditch. The company reported the spill, and subsequent sampling by the South Carolina Department of Health and Environmental Control (SCDHEC) found cadmium and chromium contamination in the surface water and sediment of this drainage channel. Although the release apparently was a one-time event, SCDHEC began a series of groundwater investigations at the site that included the installation of monitoring wells screened at various depths in the aquifer underlying and surrounding the lagoon.

Several of the groundwater samples collected from these wells, as well as other wells installed and sampled later, contained chromium, lead, iron, and mercury at concentrations in excess of drinking water standards. Despite these results, in 1980, the Industrial and Agricultural Wastewater Division of SCDHEC advised B&J, "We have recently completed evaluation of groundwater at Blake and Johnson with favorable results," and "there is little likelihood of finding serious contamination of groundwater." The U.S. Environmental Protection Agency (EPA) seemed to concur when, in May 1981, it released a report stating that "no action (was) needed" at the site. In November 1981, a SCDHEC interagency memo from the Ground Water Protection Division disagreed with the EPA and the Agricultural Wastewater Division conclusions and stated that, because the site is in a major aquifer recharge zone, they had serious concerns about B&J's waste disposal practices and that previous SCDHEC findings were "not consistent with our assessment of the situation."

Beaufort County is made up of about 70 islands connected by a complex series of inland and coastal estuaries and other waterways. It is a sensitive envi-

ronmental setting where tourism, recreation, and fishing are major sources of revenue. The county is home to several resorts including Hilton Head, noted for their pristine beaches and clean water. Whereas the majority of potable water for the area is provided by the Savannah River, groundwater is an important secondary, or backup, water supply in the site vicinity for both private and municipal uses.

Beaufort's Burton Well Field, approximately 2.5 miles (4 km) southeast of the B&J site, is used to supplement peak water demands between May and September (tourist season). In addition, the nearby Marine Corps Air Station and the Laurel Bay Naval Housing area rely on well water as backup supplies. A few local industries also use well water in their manufacturing operations. Most of these wells are completed in the deep Floridan Aquifer, found several hundred feet below the surface, and therefore are unlikely to be affected by operations at B&J. The presence of the cadmium, chromium, and lead in surface water and soil samples, however, was troubling for a community that was so dependent upon its water resources for prosperity and quality of life.

For business reasons not related to environmental issues, B&J ceased operations in 1980, and its successor (Independent Nail Company) changed the nature of site operations so that there were no wastewater discharges to the lagoon. During its operational life, B&J released approximately 85 million gallons (345 million L) of plating wastewater into the lagoon or surface impoundment, and some of this wastewater infiltrated into the groundwater system. Upon the basis of additional environmental investigations by the EPA and the state of South Carolina, which uncovered further soil and groundwater contamination on the property, and as a result of both discharges to the surface impoundment and generally poor handling of hazardous materials, the B&J property was added to the National Priorities List in 1984 and became a Superfund site. The investigations found chromium, cadmium, nickel, and zinc in soil samples from the B&J site at concentrations ranging from hundreds to tens of thousands of times above background or ambient values. Fortunately, this contamination was primarily confined to the upper one to two feet (0.31–0.62 m) of soil across the site and in the surface impoundment. This made cleanup much easier.

### CLEANUP OF THE SITE

The EPA selected soil stabilization and solidification as the preferred remedial technology for the B&J property. In contrast to incineration, the stabilization and solidification process does not destroy or

reduce the toxicity of the contaminant mass. Rather, it inhibits or prevents the release of contaminants to the environment and lessens the likelihood of human exposure. Soil stabilization and solidification most commonly is used for soil contaminated with metals, as its effectiveness on organic compounds has been inconsistent. There are two basic approaches used in solidifying and stabilizing contaminated soil, chemical-based systems and thermal-based systems.

### Chemical Based Systems

The solidifying and stabilizing agent traps contaminants in place, preventing leaching as water infiltrates through the stabilized mass. By far, the most common compounds used in chemical solidification systems are pozzolanic materials. These are inorganic, fine-grained, siliceous or siliceous and aluminous dustlike materials that do not form hardened cement. Pozzolanic materials also do not allow mortar and cement to cure or set too rapidly and increases its durability. The use of pozzolamics also has the added benefit that as the hazardous contaminants are encapsulated, the physical properties of the soils are changed. The soil's load-bearing capacity (strength) is increased, and its permeability is reduced, making it ideally suited for use as backfill for excavation.

Soil from the B&J property and the bottom of the lagoon was excavated and mixed into slurry with a sodium silicate (pozzolanic)/cement-based material. It was then pumped into a surface impoundment as backfill. The resulting material was a claylike substance that had a high bearing strength and solidified within 72 hours. After it hardened, six inches (15.2 cm) of topsoil was spread and grass seed was planted over the former lagoon area. Approximately 6,200 cubic yards (5,283 m<sup>3</sup>) of soil was treated in this way at the relatively low cost of about \$1.2 million, or \$194 per cubic yard.

The effectiveness of soil solidification/stabilization was assessed through a long-term monitoring program using a laboratory test known as Toxic Characteristic Leaching Procedure, or TCLP. In 1990, the EPA required that TCLP be used to simulate leaching conditions in a landfill in the presence of putrescible waste (garbage). This test also is used to identify whether a waste has certain hazardous characteristics. A sample of the B&J solidified and stabilized soil was pulverized and passed through a 0.37-inch (95-mm) screen. A sample of 0.22 pound (100 grams) of the material was then placed in a special container, called an airtight zero head extraction (ZHE) device, mixed with acetic acid, and agitated. The solution was then extracted from the ZHE container, filtered, and tested. If contaminants

are not detected in the solution above regulatory limits, then the waste is stabilized and is considered nonhazardous.

*See also* AQUIFER; CADMIUM; CHROMIUM; LEAD; NICKEL; SUPERFUND SITES; TIMES BEACH SUPERFUND SITE; ZINC.

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**Boston Molasses Disaster** *Boston, Massachusetts January 15, 1919* *WaterPollution* Environmental disasters do not always have to involve toxic substances. Sometimes, they just involve too much of a substance that is harmless in small quantities. This is the case with the Boston Molasses Disaster, or "the Great Molasses Flood," as it is also known. This was almost a defining event in the history of the city of Boston. For decades afterward, Boston smelled of molasses to the point where it was part of the character of the city. The event was celebrated in schools every 10 years on the anniversary for many decades. As with most disasters, it was the location and timing that made the Boston Molasses Disaster such a defining event.

### THE SETTING

A large molasses tank was built on the North End of Boston, Massachusetts, in 1915, by the Purity Distilling Company. The tank was 58 feet (17.8 m) high and 90 feet (27.7 m) wide, made of cast iron

plates that were sunk into a concrete base and riveted together. The tank was built to hold up to 2.5 million gallons (11.4 million L) of molasses, which was distributed to produce rum, baked beans, and industrial alcohol. Perhaps because they sensed the inevitability of Prohibition, the Purity Distilling Company sold the tank and entire complex to United States Industrial Alcohol in 1917, which produced alcohol for industrial uses only. The area around the tank was industrial and quite active. There were freight sheds of the Boston and Worcester and Eastern Massachusetts Railways, the paving division of the public works department including more than a dozen horses, the headquarters of Fireboat 31, the Charlestown Navy Yard, the wharves on the Charles River, the Boston Gaslight Building, and a residential area, all under a section of the elevated railway.

### THE EXPLOSION AND FLOOD

On January 12, 1919, the temperature was a frigid 2°F (−16.7°C) in Boston, and people stayed indoors as much as possible. A warm front passed through the next day, and the temperature rose quickly to unseasonably high temperatures. By January 15, it had reached 43°F (6°C), and the people of Boston began to spend as much time as possible outdoors. At noon on the 15th, rather than seeking shelter, many of the workers in the industrial area between Copp's Hill and the Charles River chose to eat their lunches outdoors, and children went home for lunch or played in the North End playground.

Without warning at 12:30 p.m., a deep, low rumble shook the area, followed by a heaving of the ground beneath the feet of the stunned people. This was immediately followed by the sound of ripping and tearing of steel and rapid popping like machine gun fire, as the tank rivets broke away. One plate shot away from the tank with such force that it sheared off the lower support for the elevated railway. Other flying plates and rivets tore apart the buildings all around the square. Then a booming roar pierced the air as the bottom of the tank split wide open, and a geyser of yellow-brown liquid shot skyward followed by a huge wave of molasses.

The tank had been filled just two days before to a height of 49.5 feet (15.2 m), so that it contained 2.3 million gallons (10.4 million L) or 14,000 tons (12,727 metric tons) of molasses. As the wave of molasses emerged from the tank and onto the open area, it was 15 feet (4.6 m) high and traveling at 35 miles (56 km) per hour. As it moved, it exerted a forward pressure of two tons per square foot (1,814 kg/m<sup>2</sup>) that literally crushed most buildings that it hit, and, after it passed, it created a vacuum that was

strong enough to destroy the remaining structures and pulled objects into it. The molasses flowed with a hissing and sucking sound as it destroyed everything in its path. Those people who were not killed in the initial explosion were pulled into the molasses, which was so viscous that victims simply sank into it and disappeared no matter how hard they struggled. The horses at the public works department were sucked in and crushed or drowned, as were the people. It knocked out the support for the elevated railway, and the tracks slowly sank down. The alert engineer of an oncoming train saw the tracks begin to sag and braked the train in a panic. It stopped in time to see the sagged part of the tracks disappear into the molasses flood. The train went off the track, but its passengers were safe.

As the wave hit the freight offices, it was still five feet (1.5 m) high. It crushed the doors, windows, and some of the facing walls and crushed the goods and the clerks who were working there. The molasses was so heavy that it collapsed the floor, crushing and drowning the workers in the basement. Some who survived the initial collapse tried to run up remaining stairs, but all the molasses had to do was engulf the ankles of the victims to trap them. It was so thick and sticky that it immobilized the victims' legs upon contact, and they helplessly disappeared into the gooey mess no matter how much force they exerted with their muscles.

The wave picked up the loaded freight cars and propelled them like missiles through buildings and ultimately crushed them as well. It knocked over the firehouse and carried it toward the sea. The wave continued into the residential area, as well, crushing and carrying away houses and anything else in its way. The wave washed over the Boston streets during the school lunch hour, and a number of young students, having gone home for a quick snack or sandwich, were on the streets. Several of them were also engulfed and killed. The wave thinned as it spread out but could not flow up the hills to the south and stopped after the short few minutes of terror it had inflicted.

### RESCUE AND RELIEF EFFORTS

A policeman in the area was calling headquarters at the time of the explosion and reported the disaster as it was happening. The first alarm to the nearest surviving fire station went out at 12:40 p.m., just 10 minutes after the explosion. Every form of rescue equipment was raced to the scene from all over the city. Once they arrived, however, the task of rescuing anyone from the thick standing molasses was not easy. The first arrivals were 116 sailors from the light



ship *USS Nantucket*, training vessel that was docked in the harbor, but they could only rescue people at the edge of the flood. Next the Boston police, Red Cross, army, and other navy personnel arrived but had the same trouble reaching people. Finally, the Boston firemen laid ladders horizontally out over the molasses and crawled out on them in an effort to pick up the injured, dead, and dying. Fifteen bodies were recovered that day and another six would be recovered over the next three days for a total of 21 fatalities. The last two bodies recovered, three days later, were so battered and crystallized in the molasses that they could not be identified. There were also 150 injuries caused by the disaster. Many of these people were quickly taken to nearby hospitals by whatever means available. There were so many injured people, however, that several doctors set up a makeshift treatment center in a nearby building.

### THE CLEANUP

As the people of Boston tried to clean up the two to three feet (0.5 to 1 m) of standing molasses that covered a significant part of the downtown area, it quickly became obvious that it would be no easy task. Firemen hosed down buildings to wash them off, a miserable job in the cold January weather. Fireboats sprayed saltwater on the streets in an effort to remove the molasses, but the spraying caused it to froth up into a yellow foam that just spread it farther. That which was washed into the harbor turned the water brown, and a sticky film coated all ships and boats that passed through. Sand was dumped on all of the molasses that remained. About 87,000 hours were devoted to the cleanup. Ironically, on the night of January 16, the cleanup was halted when all the church bells in the area began ringing to proclaim that Nebraska had just cast the deciding



Devastation caused by the explosion of a molasses storage tank in Boston, Massachusetts, January 15, 1919—in the background is Charlestown Navy Yard (AP Images)

vote on the Eighteenth Amendment, and Prohibition became law.

Cleanup did not proceed as smoothly as desired. All the rescue workers, cleanup crews, local workers, and residents, and droves of sightseers walked through the molasses, sand covered or otherwise. The molasses on their boots was spread over the rest of Boston and out into the suburbs. Everything in the city was sticky, from streetcar seats to public telephones to the floors of every store and public building. It was even reported to have spread as far away as Worcester, Massachusetts. The smell of molasses lingered in Boston for years.

### LAWSUITS

There were about 125 lawsuits filed against the United States Industrial Alcohol Company for damages and wrongful deaths. It was the longest set of hearings for a single case ever in the history of the Massachusetts courts, lasting about six years. There were so many lawyers that they could not all fit into the courthouse, so two were chosen to represent all of the claimants. There were more than 3,000 witnesses, many of them expert witnesses, giving 45,000 pages of testimony. Never in the history of New England had so many engineers, metallurgists, and scientists been asked to testify. One structural engineer testified for three weeks straight, several times until 10 in the evening. In the end, it was decided that the “factor of safety” was too low in the incident, and the United States Industrial Alcohol Company was held liable. The actual cause of the explosion was fermentation in the tank, causing excessive pressure that exceeded the strength of the tank. The warming weather accelerated fermentation. The company paid a little less than \$1 million in damages to settle all of the claims or about \$12.1 million in 2009 dollars. It is reported that families of those killed received about \$7,000 apiece, about \$85,000 in equivalent 2009 money.

See also WATER POLLUTION.

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### Braer oil spill Shetland Islands, Scotland January 5, 1993 Water Pollution

In 1975, at the Oshima Shipbuilding Company in Nagasaki, Japan, the keel was laid for a single-hull, oceangoing tanker with a deadweight tonnage–cargo capacity of about 100,000 tons (90,000 metric tons), or approximately 25 million gallons (114 million L). Measuring 780 feet (240 m) long and 130 feet (40 m) across, the ship was built to cruise at 14 knots and equipped with the most up-to-date navigational aids and control systems. Delivered as the *Hellespont Pride*, the ship performed adequately and was sold in 1989 to Bergvall & Hudner (B&H), a Norway-based shipping company. It was one of some 15 ships in this company’s growing fleet that were purchased with the proceeds of an initial public offering. Renamed the *Braer* (an acronym of the two owners’ names), it was registered in Monrovia, Liberia, and chartered to Ultramar, Ltd., a Canadian oil company. On January 3, 1993, the now almost-20-year-old tanker picked up a cargo of 93,170 tons (84,700 metric tons) of light North Sea crude oil from a refinery and terminal at Mongstad, Norway. Bound for Canada, the *Braer* planned to sail westward, through the North Fair Isle Strait, across the North Sea, eventually berthing at Quebec to off-load.

### THE ACCIDENT AND SPILL

Ocean conditions in the North Atlantic in early January are characterized by gale force winds, bitter cold temperatures, and very rough seas. The experienced crew of the *Braer* was prepared for the voyage, obtaining current weather forecasts and having made this or similar trips many times. Clearing the Mongstad harbor, the *Braer* immediately was buffeted by strong southerly winds, and during the early morning hours of January 4, as a result of the pitching and yawing of the ship, several pieces of spare steel pipe tore loose from their straps and began rolling around the port side of the deck, crashing into the engine casing. The crew eventually secured the pipes and inspected the engine casing for damage, but did not find any.

As with many ships of its generation, the *Braer* was fueled with a heavy No. 6 fuel oil also called Bunker C. This oil was so viscous that it needed to be heated to thin it out for use in the ship’s engines, which turned the *Braer*’s single propeller. An auxiliary, or supplemental, boiler was used for this purpose. During the evening of January 4, the auxiliary boiler was taken off-line for routine adjustments. Once these were completed, the crew was unable to restart it. Without the auxiliary boiler, the Bunker C





**Oil-covered cormorant killed as a result of the tanker *Braer* running aground and leaking off Garths Ness, Shetland Islands, Scotland, 1993 (Ian Cook/Time Life Pictures/Getty Images)**

could not be used, so the engine room crew switched to its backup system of thinner, No. 2 diesel fuel.

Around midnight, the crew found that seawater was present in the oil supply line to the boiler, thus preventing the auxiliary boiler from relighting. As they attempted to drain the seawater and relight the boiler, seawater also was found in the oil supply service line to the main engine and generator, which powered the ship's electrical systems. Shortly before 5:00 A.M., the main engine stopped, fouled by seawater in its fuel. A few minutes later, the main generator shut down, and the ship was floating in heavy seas with only minimal lighting and radio control systems working off emergency batteries that were quickly being drained.

The ship was drifting northward under an unrelenting force 10 southern wind, which included 20–30 foot- (6–9 m-) high waves with overhanging crests, a white sea with densely blown foam, and heavy rolling. The position of the *Braer* when the engines failed was 10 miles (16 km) south of the Shetland Islands. These are Scottish territories of the United Kingdom, lying about 100 miles (160 km) northeast of the Scottish mainland. The Shetland Islands are made up of about 100 islands, 15 of which are inhabited. The sea dominates the Shetlands culture. Fishing and tourism are vital parts of this small archipelago's economy. Alerting the Scottish Coast Guard, the *Braer* called for a tow, but by early morning the ship had moved to within four miles (6.4 km) of Sumburgh Head and was in danger of grounding. Through a series of dangerous maneuvers, most of the 34 crew were evacuated by helicopter, while the captain and some engine room staff volunteered to remain onboard to try to restart the engines, boiler, and generator. By midmorning,

the *Braer* had drifted to within 0.5 mile (0.8 km) southeast of Horse Head Island, and the rest of the crew was taken off by helicopter.

By now, two seagoing tugboats had arrived and attempted to secure towlines, but the rough seas and the fact that no crew remained on the *Braer* to help fasten the lines made it impossible. Miraculously clearing Horse Head Island, thanks to a strong westward tide, the *Braer* once again began to drift north, and a party of volunteers, including the captain, were dropped onboard to try to attach messenger lines shot over from the seagoing tugboats. Messenger lines, also called shot lines, are thin cables that are propelled by pneumatically fired cannon or cylinders from the tug onto the deck of the disabled vessel. One end of the messenger line is connected to a thick towing cable, and the crew of the disabled vessel attaches the other end to a manually operated winch. The winch then is used to haul the towing cable aboard the disabled vessel, where it is fastened to special deck cleats or the ship's heavy mooring lines. After the two vessels are joined by the cable, the disabled ship is taken in tow.

While the volunteer crew struggled to receive and attach the messenger lines, at one point almost being able to make the critical connection before the raging sea tore the line from their hands, the *Braer's* luck finally ran out and it went aground on the west side of Garth's Ness at approximately 11:20 A.M. on January 5, 1993. Oil immediately began to gush into the sea and, fearing a fire or explosion, the coast guard ordered the ship abandoned.

The *Braer* was fully loaded with Gulfaks crude oil. In Europe, crude oil is priced on the basis of comparison of its physical characteristics to reference oil. Brent crude, or oil from the Brent oil field in the North Sea, is the benchmark against which oil from all other North Sea oil fields is measured. Gulfaks crude is light (low-density) oil from a well-developed field in the North Sea near Norway. This type of oil is more easily dispersed and broken up than some other types of thicker, heavier North Sea crudes. Over the next 12 days, as the large waves and overpowering winds relentlessly pounded the *Braer*, the ship broke into three pieces and the entire cargo and onboard fuel supply were discharged onto the coast of Garth's Ness, near Scalloway, the busiest fishing port in the Shetlands. Approximately 1,650 tons (1,500 metric tons) of Bunker C, the fuel used to power the ship's engines and generator, also was released as a result of the grounding.

The *Braer* disaster was the 11th largest oil spill in maritime history. Later investigations by the *Braer's* owners and insurers, as well as the Scottish government, found that the air intake pipes inside

the engine casing were damaged when spare steel pipes broke loose in the heavy seas and repeatedly smashed against the side of the engine compartment. These broken intake pipes allowed seawater to enter and contaminate both the diesel fuel and Bunker C oil supplies.

### THE CLEANUP

The heavy seas and high winds prevented the use of skimmers or other types of mechanical oil collection devices, and even chemical dispersants were used only on a limited basis. The roiling seas and blustery winds acted to break up and volatilize the light crude oil as it poured out of the hull of the *Braer*. So intense was the weather that a measurable oil slick never formed and the floating hydrocarbon was quickly dispersed or mixed within the water column. Typical seawater contains oil at concentrations of around three parts per billion. Within the immediate vicinity of the *Braer*, as oil was emptying into the sea, ocean-water samples contained concentrations of petroleum hydrocarbons in the hundreds of parts per million. As the oil dispersed, hydrocarbon concentrations dropped to 50 ppm, still several thousand times higher than normal. Even two weeks after the spill, oil was present at around 4 ppm.

Subsequent studies found that much of the released oil attached to sediment stirred up by the gale. These oil-laden sediments were widely redistributed by sea-floor currents but generally tended to accumulate in two natural topographic low spots near where the *Braer* had gone aground. The oil contaminated shellfish, and a Fisheries Exclusion Zone was established along much of the coastline, preventing exploitation of this important local resource for several years. The prohibition against commercial fishing in these areas was not lifted completely until 2000.

On land, a small but dedicated band of volunteer and paid professionals struggled to rescue seabirds that had become coated with oil. They also conscientiously removed contaminated seaweed and oily debris. Some 1,500 dead and oil-covered birds eventually were found on beaches near the *Braer*. Several thousand “farmed” salmon, trapped in special submerged pens just off the coast, bore the brunt of the damage. Contaminated beyond salvation, they either died in their cages or were ordered destroyed by local health officials. Ten seals were oil-covered and their bodies found on the beach. A pair of otters survived oiling but were crushed by a news van as it rushed to cover the effects of the spill on local wildlife. Adjacent to the grounded ship, roads, farmlands, and even sheep became coated with oil as onshore breezes blew droplets inland.

### THE AFTERMATH

The 1993 tourist season for the Shetland Islands disappeared along with the *Braer*'s oil. More than \$4 million in travel, hotel, and tour bookings was cancelled and more than 200 compensation claims were filed for losses related to business interruption as well as property and livestock damage. Several health-related claims also were made, but most government studies found that health impacts were primarily minor and short-lived. Total claims, including insurance claims for the vessel and its cargo, exceeded \$100 million.

The transport of oil over the oceans is a vital part of the world's economy and a key factor in maintaining a reliable energy supply and a strong national defense for many countries. It also can be risky, and no corporation is willing to invest millions of dollars to build a tanker and operate it unless insurance is available. After the *Torrey Canyon* disaster, insurance companies became less willing to provide coverage for the large “supertankers” that were being built. Without insurance, the global transport of oil would either cease or become prohibitively expensive. The International Maritime Organization, or IMO, recognized this developing crisis and convened the 1969 Civil Liability Convention (CLC), which limited the financial liability of both shipowners and insurers for the consequences of an oil spill. The CLC clearly holds the owner of the ship responsible for the cleanup of any oil that escapes from its vessel but limits claims for damages on the basis of the vessel's cargo capacity. Signatory countries to the CLC must require oil-carrying vessels with a cargo capacity of more than 2,200 tons (2,000 metric tons) that operate in their waters to carry certain levels of insurance. If it can be demonstrated that the shipowner acted recklessly or did not take reasonable precautions to prevent the spill, then the liability is not limited.

To provide compensation when damages are in excess of the limit of liability established under the CLC, an injured party can make a claim against the International Oil Pollution Compensation (IOPC) Funds. These three funds, the 1971 Fund, the 1992 Fund, and the Supplementary Fund, were set up to help pay for property damage, including cleanup costs, incurred when oil is unintentionally released from a ship. The claim is paid from one of the designated funds to the injured party depending upon the extent of the damage and whether the damage has occurred in a country that participates in the IOPC process.

Based in London, the IOPC Funds are financed by surcharges on certain types of oil transported in oceangoing vessels. They essentially are a tax or levy



on every gallon of oil that is paid by the terminal or refinery that receives the tanker-delivered product. For damage by a seaborne release of oil, governmental agencies, private citizens, or businesses may file a claim for compensation with IOPC. The 1969 CLC set a limit of liability on the *Braer's* owners for pollution damage and cleanup costs of \$8 million. Spill victims also were able to file claims with IOPC. In total, about \$80 million was available as a total compensation pool for those damaged by the *Braer's* release. By 1996, most claims had been settled and total payouts by both the *Braer's* insurers and IOPC were in the range of \$50 million.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS; TORREY CANYON OIL SPILL.

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**brownfields** Certainly the goal of any environmental remediation project is to produce a "green field," in which all pollutants are removed and the land is restored to its prepollution productive state. In many cases, the cost of remediation and subsequent monitoring is so prohibitive that it is more cost-effective for companies and individuals just to pay the taxes on the affected property, fence it off, and let it lie fallow indefinitely. Many such sites are within thriving urban areas and form a blight on the community, slowing economic growth by suppressing property values and sequestering valuable land that could otherwise be a thriving business. The U.S.

Environmental Protection Agency (EPA) recognized the problem and in 1995 devised a program to allow companies and communities partially to restore severely polluted property, called brownfields. The program is, therefore, a compromise economic redevelopment program for polluted properties. The official EPA definition of brownfields is

a property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.

If the site under consideration meets the criteria of severe pollution under several federal designations such as the Solid Waste Disposal Act, Federal Water Pollution Control Act, Toxic Substances Control Act, or Safe Drinking Water Act, it can be partially restored to meet certain purposes. It may never be a park or a playground, but it can be a parking lot, a warehouse, or even a manufacturing plant for certain industries. To accomplish this restoration, the more toxic of the pollutants must be removed and the rest reduced to acceptable levels for the proposed purpose. The property must be inspected and pass certain remediation criteria before any redevelopment can take place. It also must be monitored for the life of its use.

The idea of brownfields legislation is that it encourages at least the partial remediation of otherwise highly and indefinitely polluted properties. It increases the local tax base, facilitates job growth, utilizes existing infrastructure, reduces development pressures on undeveloped open land, and ultimately improves and protects the environment. It is a method for urban renewal in older cities with an industrial heritage. The EPA estimates that there are more than 450,000 brownfields in the United States. As a result of the Small Business Liability Relief and Brownfields Revitalization Act, the program includes significant funding in the form of grants including assessment grants to evaluate the potential problem, revolving loan fund grants to aid in actual remediation, job training grants for environmental training of the community, and cleanup grants for direct remediation of properties with planned non-profit use. The brownfields program has many individual success stories but in general has leveraged more than \$6.5 billion in brownfields cleanup and redevelopment funds from a variety of sources, leading to the creation of more than 25,000 new jobs.

Examples of success stories in the brownfields program are plentiful. Through a \$200,000 EPA Brownfields Pilot grant to the city of Dallas, Texas, in September 1995, more than \$550 million in



Former Bethlehem Steel plant, now a brownfield in Pennsylvania (Christopher Russo; used under license from Shutterstock, Inc.)

public and private funding was leveraged toward cleanup and redevelopment of polluted areas in low-income neighborhoods. More than 900 jobs were created through brownfields cleanup and redevelopment efforts that included the construction of a housing complex and a shopping center, among others. Glen Cove, New York, received a pilot grant from the EPA to redevelop its run-down waterfront area. The grant helped the city leverage approximately \$20 million in grants and assistance from various government agencies. As a result of this improvement and commitment, private development invested in renewal of a number of properties along the waterfront. The city's overall Revitalization Project is generating almost \$200 million in annual sales and \$10 million in taxes and created more than 1,700 jobs. In Clearwater, Florida, a \$200,000 grant yielded one of the most successful brownfields restoration efforts in Florida. It involved a 14-acre (5.7-ha) site of an auto service center that was resurrected into Information Management Resource's (IMR) Global Center headquarters. The project resulted in more than \$51 million in capital investment and was the largest business deal in the city's history. Redevelopment resulted in the construction of six buildings with a total of 310,000 square feet

(28,800 m<sup>2</sup>) of office space. In Bridgeport, Connecticut, a small \$200,000 brownfields grant from the EPA to evaluate polluted property in a prime location was leveraged into more than \$12 million in investments that built a number of structures including a new baseball stadium. In Birmingham, Alabama, a \$200,000 grant was used to address a polluted and abandoned industrial area that was transformed into 2 million square feet (185,800 m<sup>2</sup>) of commercial and industrial space that brought more than 2,000 jobs to the area.

There are numerous other success stories from all around the United States. Although it is a stopgap program, brownfields has resulted in a significant amount of environmental remediation that would not otherwise have been accomplished.

See also ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; SAFE DRINKING WATER ACT.

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**Bunker Hill Complex Shoshone County, Idaho (1975–1983) Soil Pollution** The Bunker Hill Mine Superfund Site (also called Bunker Hill Company or Bunker Hill Mining & Metallurgical) is in Shoshone County in the panhandle region of northern Idaho, approximately 40 miles (64.4 km) east of the city of Coeur d'Alene between Washington and Montana. Placed on the National Priorities List (NPL) as a Superfund site by the U.S. Environmental Protection Agency (EPA) in 1983, the 21-square-mile (54.4-km<sup>2</sup>) property is contaminated by the residues of lead mining and smelting operations that began in the late 1880s and is one of the largest Superfund sites in the United States.

### BACKGROUND ON THE MINES

The first mines in Shoshone County opened in 1889, extracting lead and silver ores from mineralized veins in Precambrian metamorphosed quartzite and argillite. As geologists and prospectors found more high-grade ore, mining operations expanded, and, in 1917, a lead smelter opened to process and refine ores locally. The population of the area, now nicknamed "Silver Valley" because of the large number of mines, grew rapidly with most people living in the newly established towns of Kellogg, Smelterville, Wardner, and Pinehurst. At its peak of production, the mine area covered 6,200 acres (2,509 ha), was more than one mile (1.6 km) deep, and had nearly 125 miles (201.2 km) of underground roads, adits (horizontal access tunnels), and shafts.

Several features of the Silver Valley ore deposits made them attractive for large-scale mining activities. The area was sparsely populated, and inexpensive land was readily available for the development of infrastructure and support facilities including processing mills, machine shops, and worker housing. The ore was relatively close to major industrial markets on the West Coast and in the Midwest, and

the coal deposits of Montana and Wyoming that would supply the energy needed for processing the ore were nearby. Also, the South Fork of the Coeur d'Alene River flowed through Silver Valley, emptying into Lake Coeur d'Alene, 40 miles (64.4 km) downstream, providing a dependable water supply for ore processing, local agriculture, and drinking.

The removal of metallic lead from the minerals that make up Bunker Hill ore was a three-step process: 1) The ore was crushed into small pieces, and as much non-ore rock, or gangue, as possible was removed either by hand or by mechanical sorting. 2) The concentrated lead ore then was mixed with a limestone flux or coke and heated to a temperature just below its melting point to allow a chemical bond to form with those materials, a process called sintering. 3) The sintered ore was placed in a vat or kettle and fed into a blast furnace, where the carbon in the flux or coke allowed the ore to separate as a molten lead bullion (98 percent pure lead) and sink to the bottom of the container. By-products of the process, called slag, rose to the top of the molten mass and were skimmed off as waste material.

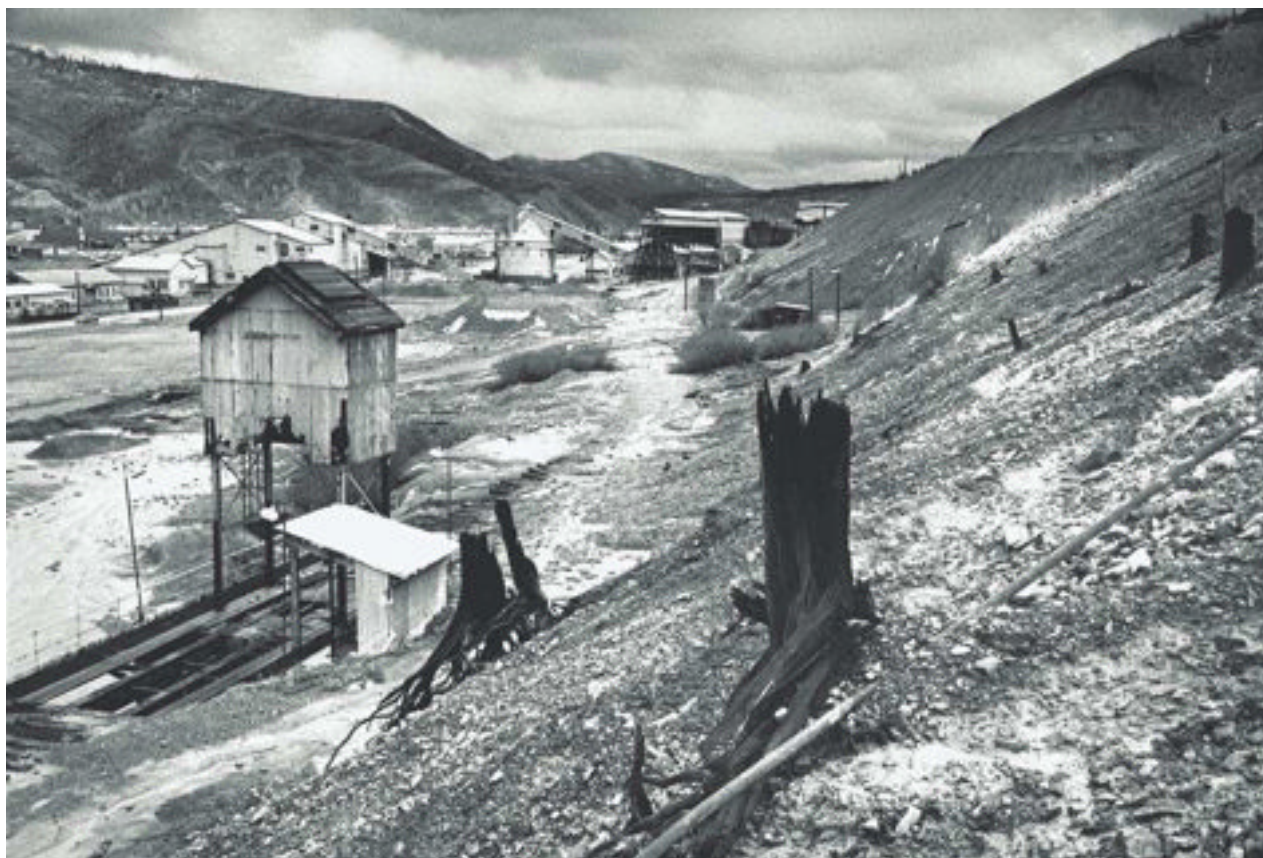
Unlike many of today's modern lead smelting operations, the process used at Bunker Hill was energy intensive and produced enormous quantities of hazardous and nonhazardous waste by-products. Consistent with practices at most mines operating at this time, mine tailings were flushed directly into the Coeur d'Alene River and its tributaries. Lead smelter slag was stockpiled on the ground, without regard to environmental impacts of contaminated runoff or blowing dust. The most significant legacy imposed upon the residents of Silver Valley from the 100+ years of mining that took place there was the lead emitted into the atmosphere.

### CONTAMINATION OF THE SITE

During processing, sintering, and melting of the ore, large amounts of lead-bearing dust were emitted. This particulate quickly settled around and in the vicinity of the mill, where it contaminated the soil, washed into surface water, and leached into underlying groundwater. The lead in this airborne dust represented a serious threat to the health of workers and local residents. Few environmental controls were in place, and particulate-laden water, generated by the washing and processing of lead-bearing ores, was piped directly into either the Coeur d'Alene River or its tributaries. Water was pumped from the mine. Slag was strewn around the valley, close to the mills or wherever it was easiest to place.

By the early 1900s, environmental conditions had deteriorated to the point that even the mine operators





Effects of acid rain on the local ecosystem near the Bunker Hill mine and smelter complex, Idaho, 1991 (© Dan Lamont/CORBIS)

thought changes had to be made. A baghouse was constructed, in 1923, to capture particulate emissions from the smelter. Fumes and dust from lead refining passed through a series of cloth traps, where some of them would be captured. This was only partially effective, and large quantities of lead-bearing particulate still were released from the smelter for another 50 years. In 1938, a central impoundment basin (tailings pond) was constructed on the eastern edge of the Coeur d'Alene River's outwash plain, north of the Bunker Hill Complex. Constructed of low-grade ore and waste rock, the 70-foot- (21.3-m-) high walls of the basin were designed to receive and hold process and mine water, allowing particulate matter to settle out prior to discharge to the Coeur d'Alene River. Like the baghouse, the tailings pond was only partly successful in controlling releases of lead wastes from the Bunker Hill Complex.

Throughout the 1940s and 1950s, mining and processing at the Bunker Hill Complex rapidly expanded, with both workers and residents hesitant to complain about deteriorating environmental quality. Mining provided secure, high-paying jobs, and the economic health of the community depended on the ability of the mining companies in Silver Valley

to produce lead quickly and cheaply. During the 1970s, Bunker Hill was the second largest smelter in the United States, producing nearly one-fifth of the processed lead in the world and more than 20 percent of the country's lead and zinc. Between 1965 and 1981, the smelter released more than 6 million pounds (2.7 million kg) of lead into the atmosphere. Lead emissions increased sharply in 1973, after a fire destroyed a major portion of the baghouse. Company officials, however, decided to continue to operate, using a patchwork of particulate control measures that did little to control emissions. The reason for the haste was primarily that the price of lead was near an all-time high (\$479 per ton, or \$436 per metric ton).

### PUBLIC HEALTH OUTCRY

As public awareness of the dangers of lead increased, political pressure mounted to investigate the effects of mining on the health of those working and living near Bunker Hill. From the 1930s through the 1950s, worker's unions made several unsuccessful attempts to change operating conditions at the smelter and in the mine. It was not until the 1970s, with the passage



of the Federal Clean Air Act and Clean Water Act, that significant environmental improvements began to be made. A \$1-million wastewater treatment plant was constructed at the tailings pond to treat effluent being discharged to the Coeur d'Alene River; however, this effort did not address lead leaking into groundwater through the bottom of the unlined pond. By 1975, the baghouse had been modernized and its flue systems cleaned, repaired, and sealed.

The company operating Bunker Hill, however, fought these and other mandated environmental requirements with an aggressive public relations and lobbying campaign. It hired two public relations companies to publicize its efforts at pollution control. The company purchased homes within a half-mile (0.8-km) radius of the smelter, burned them, and brought in fresh topsoil in a futile effort to revegetate the area. While the company was trying to clean up its environmental image, concern about lead poisoning of workers and their families prompted the Idaho Department of Health & Welfare to test levels of lead in air, soil, and vegetation. Results indicated very high concentrations of lead were present in the environment.

Company officials quietly commissioned their own study, and, in an outrageous breach of medical ethics, urine samples from children in the area were collected and tested without informing the parents or obtaining their consent. The company then refused to release test results. Public outcry and the desire to avoid a study by the Federal Centers for Disease Control forced the company to cosponsor and fund the Shoshone Lead Health Project, a medical monitoring program designed to evaluate blood lead levels in local area children. In January 1975, the results were made public, and of the 172 children living closest to the smelter whose blood lead level had been tested, 170 had lead levels above 40 mcg/dL, the level at which hospitalization is recommended. Emergency medical intervention is recommended at blood lead concentrations above 70 mcg/dL, and 45 children had blood lead levels above 80 mcg/dL. In fact, one of the children tested had more than 160 mcg/dL, the highest blood lead level ever recorded in the United States.

### ENVIRONMENTAL ACTION AND CLEANUP

Investigators found that lead emissions entered soil and water as well as air. For years, mine and smelter tailings had been used to sand icy streets in winter and as backfill around new construction. Lead was broadly dispersed through the Coeur d'Alene River basin and was being connected with the deaths of aquatic organisms, native fish, and hundreds

of migratory waterfowl. Despite several last-ditch efforts to keep the environmental situation under control, the final straw for the Bunker Hill industrial complex occurred in June 1980, when the U.S. Court of Appeals upheld the EPA ambient air quality standard for lead (1.5 mcg/m<sup>3</sup>). By 1982, despite having spent more than \$20 million for pollution control, Bunker Hill could not meet this requirement or other, more stringent environmental standards. As a result, the mine and smelter closed, and 2,000 people lost their jobs.

In 1983, the Bunker Hill Industrial Complex was added to the National Priorities List as a Superfund site. The U.S. Environmental Protection Agency, in cooperation with the state of Idaho, started the cleanup of thousands to millions of tons of mill tailings, mine waste rock, unprocessed ore concentrates, and lead-contaminated soil spread over more than 21 square miles (54.4 km<sup>2</sup>). Included with these materials were the physical facilities associated with the mine, the concentrator, lead smelter, electrolytic zinc plant, phosphoric acid and fertilizer plant, cadmium plant, sulfuric acid plant, and a number of mills. A 200-acre (81-ha) unlined tailings pond also needed to be addressed. This pond was releasing, on average, about 700 pounds (317.5 kg) per day of lead and other metals into the groundwater.

Early cleanup actions included the removal of lead-contaminated soil from 16 public areas (parks, playgrounds), as well as from about 2,000 private and commercial properties. The mine operator filed for bankruptcy in 1994, and tax money had to be used to fund the majority of these efforts. Contaminated materials have been taken back to the site and buried in a specially designed containment area. The major industrial buildings also have been demolished and disposed of in the containment area. A 32-acre (13-ha) mine waste and demolition debris landfill at the former lead smelter was closed and capped, and more than 1.25 million cubic yards (1 million m<sup>3</sup>) of contaminated soil was secured and disposed of on-site. The South Fork of the Coeur d'Alene River was temporarily rerouted so that 30,000 cubic yards (22,937 m<sup>3</sup>) of contaminated sediment could be removed. A three-year outwash revegetation program was initiated to reduce levels of windblown (lead-contaminated) dust.

Although much remains to be done, there are signs that the local environment is beginning to improve. Blood lead levels in children have dropped significantly, to an average of 6 mcg/dL (less than 10 mcg/dL is considered a safe blood lead level), and significant numbers of trout have returned to the South Fork of the Coeur d'Alene River. Bunker Hill remains one of the worst examples of lead poisoning

and environmental contamination in the world. It took almost 50 years for local residents and government officials to recognize the dangers associated with the lack of acceptable pollution control practices in effect at the mine and smelter. The problems were finally recognized and are being addressed.

See also CADMIUM; INORGANIC POLLUTANTS; LEAD; SUPERFUND SITES; ZINC.

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**Burmah Agate oil spill Houston, Texas November 1, 1979 Water Pollution** By the late 1890s, it had become apparent that the fuel powering the world's economies was shifting from coal to liquid petroleum. David Sime Cargill, an enterprising young Scotsman and already a well-established businessman with warehouses and shipping interests in Ceylon (now Sri Lanka), recognized this trend and founded the Burmah Oil Company (BOC) to gain an early foothold in this new industry. Teaming with another upstart oil company, British Petroleum (BP), Cargill focused his oil exploration, development, and marketing activities primarily within the Indian subcontinent including India, Bangladesh, Bhutan, Pakistan, Nepal, Afghanistan, and Myanmar. The Burmah Oil Company also helped discover and develop major oil fields throughout the Middle East.

As the company grew, it became a more dominant factor within this region's petroleum market. In 1965, BOC was a party to a major constitutional lawsuit in the United Kingdom. During World War II, British army saboteurs blew up BOC-owned oil fields and plantations in Burma (now Myanmar)

to prevent their use by the Japanese. BOC sued for compensation, claiming that the government had, in effect, requisitioned its property and that BOC was due restitution. The House of Lords ruled in favor of BOC, but Parliament quickly passed the War Damages Act of 1965, which indemnified the government from these types of claims. This decision maintained the undue financial burden on the company.

By the early 1970s, BOC was having financial difficulties, and the company was restructured. One of the core businesses it sought to continue was the overseas shipment of crude oil. In 1974, BOC's 772-foot- (238-m-) long merchantman tanker M/T *Burmah Agate* was regularly picking up or delivering up to 400,000 barrels (about 17 million gallons [64.4 million L]) of crude oil to destinations around the world. Registered in Liberia and manned by a mostly Taiwanese crew of 35, the *Burmah Agate* was a frequent visitor to ports in the United States, Europe, and Asia.

#### THE ACCIDENT AND OIL SPILL

On what would become its last voyage, early in the morning of November 1, 1979, the *Burmah Agate* was inbound to the Houston ship channel, making its way toward one of the numerous refineries and terminals that dot this stretch of inland waterway. The Houston-Galveston Ship Channel is the busiest commercial waterway in the United States, with more than 50 ships and more than 300 barge movements taking place on a daily basis. The 50-mile- (80.5-km-) long channel first opened in the late 1800s to break Galveston's stranglehold on commerce into and out of Texas. Today, it is 45 feet (13.7 m) deep and 530 feet (161.5 m) wide. Islands in the ship channel are constructed from dredge spoils and have been designed to serve as bird sanctuaries and wildlife habitat.

The *Burmah Agate* was carrying a full cargo of blended oil with heavier Nigerian crude. Crude oils are often blended or mixed in the pipeline or during loading to improve their handling characteristics and to increase sale price. Heavy crude oils, those that are particularly viscous or thick, such as bitumen, are not readily pumpable at typical surface temperatures and pressures. To help get them physically through the pipeline or refinery, they are sometimes mixed with lighter-weight, more expensive oils. This decreases their viscosity and eases handling. Blended oils also command a higher price than the thicker, lower-grade crude oils because blending also reduces other undesirable features such as acidity or sulfur content. The objective of the blend's “recipe” is to make sure the value of a batch of blended oil



The oil tanker *Burmah Agate* on fire at Galveston Harbor entrance, Texas, on November 1, 1979 (Office of Response and Restoration, National Ocean Service, NOAA)

is greater than the sum of the value of the original crude stock and the value of lighter-weight oils used in the mixing process.

When the *Burmah Agate* was at anchor about five miles (8 km) off the Texas coast, waiting for clearance to enter the ship channel and still well outside the then-three-mile (4.8 km) territorial limit of the United States, with clear skies but rough seas (eight-foot [2.4-m] swells) and in a well-marked shipping channel, it was struck by another Taiwanese-owned ship, the 482-foot- (146.9-m-) long freighter *Mimosa*. The *Mimosa* had just dropped off a load of Japanese steel and was cruising back toward the open waters of the Gulf of Mexico. The collision tore an eight-foot- (2.4-m-) high by 15-foot- (4.6-m-) long hole in the single hull of the *Burmah Agate*, and oil began to pour from the ruptured storage tanks. The *Burmah Agate* immediately burst into flames, and 32 of its crew died almost instantly. Most of the bodies were not immediately recovered, either incinerated at the time of impact or blown overboard. They washed up on Galveston beaches or were found in fishing nets for many weeks after the accident.

The *Mimosa* also caught fire and U.S. Coast Guard helicopters, flying numerous sorties through the smoke and flames, airlifted the crew to safety. The *Mimosa* was a freighter and only carried the fuel it needed to operate but still presented a serious threat. The fire had prevented the crew from shutting off the engines, and the ship, with the starboard anchor set and dragging along the sandy bottom of the gulf, sailed unmanned and out of control in a widening spiral toward a series of submerged capped natural gas wells. The U.S. Coast Guard's on-scene commander, in a daring move, ordered a nearby tug to deploy a thick plastic towrope directly in front of the *Mimosa*. As it sailed over the towrope, the propeller, or screw, became entangled and jammed, and the *Mimosa* was rendered a floating derelict. The deck fires eventually were extinguished, and the *Mimosa* was towed back to Galveston for repairs. If the towrope had not been successful in disabling the *Mimosa*, the U.S. Coast Guard on-scene commander later said, he had been prepared to ram the ship with his own to stop the *Mimosa's* out-of-control progress toward the capped natural gas wells.



Meanwhile, the *Burmah Agate* continued to burn and leak oil. With *Burmah Agate* dead in the water, and with only five of the crew accounted for and most of them critically injured, the owners of the ship quickly assumed responsibility for the cleanup and containment of the oil. They retained a company to fight the fire while another was contracted to minimize the spread of the leaking oil. The oil burned as it cascaded from the *Burmah Agate* and quickly formed a slick about 200 yards (183 m) wide and nearly 1 mile (1.6 km) long. Prevailing winds at this time of year were out toward the open waters of the Gulf of Mexico and helped prevent an immediate ecological catastrophe. Booms and skimmers were deployed to contain the oil within the immediate vicinity of the wreck, and thousands of gallons of foam were sprayed onto the ship to attempt to control the fire.

Firefighting boats created a water curtain, cooling the decks and hull of the *Burmah Agate* that were not ablaze. This allowed a ship to get close enough to pour foam into one of the *Burmah Agate*'s flaming cargo bays. The foam extinguished the fire, but a thunderous explosion tore the ship in half when hot embers ignited explosive vapors that had been given off by the near-boiling oil. At this point, the U.S. Coast Guard declared any attempt to fight the fire too dangerous and decided to let the *Burmah Agate* burn itself out. It took eight weeks, until just after the New Year, for the fires to subside. On January 8, 1980, the fire was declared out and the oil remaining in the bays was lightered (transferred) to another tanker. The *Burmah Agate* was towed to Brownsville, Texas, where, a few weeks later, it was cut up for scrap.

### THE CLEANUP

As the fire burned, the oil still leaked from the tanker, and, by the middle of November, the resulting oil slick had grown to more than 12 miles (19.3 km). By early December, the slick was almost 20 miles (32.2 km) long. A few days after the collision, the prevailing winds changed direction and speed, and, as a result, oil overtopped the containment booms and was washed ashore at Galveston Island, San Jose Island, and Padre Island. Stiff ocean currents, associated with winter weather patterns in the gulf, also forced the oil underneath many of the booms. The oil slick from the *Burmah Agate* fouled approximately 120 miles (193.1 km) of beach.

Cleanup operations included the use of backhoes to scrape contaminated sand into trucks for disposal. This method, however, was found to be

too destructive, and special vacuum trucks were used to suck oil, tar balls, and contaminated sand from the beaches. Some 400 paid professionals and volunteers participated in beach cleanup efforts. As shoreline operations continued, oil containment activities around the *Burmah Agate* were made less effective as the booms regularly caught fire and had to be replaced; some 4,000 feet (1,219 m) of boom burned during the cleanup effort. Special skimmers taken in to back up the booms were sometimes ineffective, often becoming entangled in the booms or being damaged by other recovery vessels or ship channel traffic. A late November storm also shut down both sea and land oil containment efforts for almost a week. Despite these problems, cleanup efforts were declared complete on November 27, 1979. Beach cleanup, oil containment, and firefighting were estimated to cost approximately \$200,000 per day over the response effort. This did not include the value of the cargo or the replacement/repair costs for both ships.

### THE AFTERMATH

Later studies estimated that almost 48 percent of the oil onboard the *Burmah Agate* (about 200,000 barrels, or 31.8 million L) was consumed by the fire. Another 38 percent (about 160,000 barrels, or 25.4 million L) was saved and pumped off the ship into salvage vessels. The booms and skimmers contained slightly less than 2 percent and the remainder was either dispersed at sea (12 percent or approximately 50,000 barrels, or 7.9 million L) or washed up on various Texas beaches, estimated at less than 1 percent, or about 2,100 barrels (33,400 L).

The oil that made its way onshore from the *Burmah Agate* had no significant direct or indirect economic impacts on the local commercial fishing industry. Despite the spectacular nature of the event, the decision by the U.S. Coast Guard to let the oil burn, coupled with aggressive containment of the slick, greatly aided in protecting marine ecology.

An economic impact analysis conducted on the effects of the spill found that there was only a modest decline in tourism along the Texas coast that year, and it was most noticeable in the South Padre Island area. The Burmah Oil Company filed a \$10-million lawsuit against the owners of the *Mimosa* (Juniper Shipping), claiming it was the *Mimosa*'s navigational error that had caused the spill. Later, as the Burmah Oil Company started to expand in the 1990s, acquiring well-known U.S.-based Castrol Oil, it soon ran into financial trouble. In 2000, its long-term partner BP acquired



Burmah-Castrol, as BOC had renamed itself. The bodies of 15 of the *Burmah Agate* crewmen were never found.

*See also* BEACHES; CONTINENTAL SHELF; OIL SPILLS; WATER POLLUTION.

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**cadmium** Cadmium is a naturally occurring metallic element in rocks and minerals that is most commonly associated with zinc minerals but may also be found with copper and lead, among others. Most cadmium occurs as a minor substitution for zinc in minerals because it has similar properties, but it usually makes up less than 1 percent of the mineral. On the whole, the ratio of zinc to cadmium in zinc deposits is about 400 to 1. Some phosphate ores also contain cadmium in the parts per million (ppm) range, and it can wind up in fertilizers as a result. Cadmium-based minerals are rare and of very minor importance. Of the 25,000–30,000 tons (22,727–27,272 metric tons) of cadmium that are released into the environment per year, half is from the natural weathering of rocks. Most of the rest is from volcanic eruptions and forest fires, and between 4,000 and 13,000 tons (3,636 and 11,818 metric tons) from anthropogenic sources. It is very fortunate that cadmium is relatively rare in the natural environment because it has virtually no benefits, interfering with the absorption of other necessary nutrients such as zinc in most organisms. It occurs in significant quantities in at least 776 of the first 1,467 hazardous waste sites on the U.S. Environmental Protection Agency (EPA) National Priorities List (NPL), making it an important contaminant of concern in the United States. It is ranked the seventh worst environmental pollutant of the 275 listed on the 2007 CERCLA Priority List of Hazardous Substances as a result of this widespread distribution and adverse health effects from exposure.

### PRODUCTION AND USE

Cadmium is an inorganic heavy metal that occurs naturally in rocks, minerals, soils, and volcanic eruptions. It is also used in several industrial processes in many general-use applications and as an important metal in military applications. Cadmium was not discovered until 1817 because it generally occurs so intimately with other metals and in such small quantities that it was difficult to isolate. It is typically a zinc refinery by-product, most commonly in China, Japan, and Korea but also in Mexico, the United States, India, Great Britain, the Netherlands, Peru, and Germany. U.S. production of cadmium declined from 3,150 tons (2,860 metric tons) in 2002 to 1,000 tons (892 metric tons) in 2006, while imports increased from 300 tons (274 metric tons) to 630 tons (574 metric tons) over the same period. The largest producing mines in the United States are the Red Dog Mine, Alaska, and the Pend Orielle Mine, Washington. The current most desirable use of cadmium is in nickel-cadmium batteries, which are rechargeable. They are commonly used in cell phones, cameras, and portable computers, among other products, but are slowly being replaced by lithium-ion and nickel-metal hydride batteries, which are environmentally friendlier. Cadmium has also been historically used in paint pigment, in metal alloys, in both black and white and color televisions, and as a stabilizing compound in plastics. Cadmium is very effective at absorbing neutrons. Consequently, it is used in nuclear reactor control rods, which dampen nuclear chain reactions, thereby keeping the fission process under control. The largest consumer

of cadmium is China, which uses it for batteries, but the worldwide demand for cadmium is slowly decreasing in response to environmental concerns.

### ENVIRONMENTAL RELEASE AND FATE

Cadmium enters the environment through several pathways, primarily through zinc, copper, and lead smelting, and in industrial inorganic chemicals, electroplating, steelworks, and inorganic pigments, in decreasing order of importance. Many of these sources are very localized (point source pollutants) and do not affect many people. The cadmium with the greatest impact on human health is that from nonpoint sources: phosphate fertilizers (41 percent), fossil fuel combustion (22 percent), iron and steel production (17 percent), natural sources (8 percent), nonferrous metals (6 percent), cement plants (2.5 percent), cadmium products (2.5 percent), and incineration (1 percent). Cadmium can enter the atmosphere from industrial plant emissions, volcanic eruptions, and burning. It is generally not a threat, except in the vicinity of cadmium industry, and most settles rapidly to the soil and water systems. In water, much of the cadmium is quickly adsorbed by particulate matter and settles into the sediment, where it can accumulate to significant amounts and pose a health threat in dredge spoils. It can be transported up to 31.3 miles (50 km) from its source, and cadmium-tainted surface water can contaminate soil in some cases. Cadmium tends to be relatively immobile in soils, attaching itself to clay and organic particles. Only a certain rare chemistry of infiltrating water can move it to the groundwater system. The states most affected by industrial cadmium releases to the environment are, in order, Arizona, Utah, Montana, Tennessee, Idaho, Missouri, and Wisconsin.

Human intake of cadmium is most commonly through foodstuffs. Recent estimates are that 95 percent of ingested cadmium is from food, of which 98 percent is from terrestrial food sources through absorption from the soil by plants and continuation up the food chain, with the remaining 1 percent from drinking water and 1 percent from aquatic foods. Cadmium bioaccumulates in the food chain. These numbers change dramatically for tobacco smokers, 50 percent of whose intake is from inhaled smoke, thereby doubling their cadmium exposure. Cadmium intake through foods has decreased steadily since the 1970s in the general public. Cadmium can be greatly concentrated at hazardous waste sites. Whereas it is typically one part per billion (ppb) in water and 250 ppb in soil, near polluted sites, it can be six parts per million (ppm) in water and 4 ppm in soil, a 16-fold increase.

### HEALTH EFFECTS FROM EXPOSURE

Breathing high levels of cadmium in air severely damages the lungs and may lead to death. Ingesting high levels of cadmium causes stomach irritation leading to vomiting, diarrhea, intestinal damage, and possible death. Long-term chronic exposure to cadmium leads to buildup in the kidneys and consequent damage as well as weakened bones. Tests on animals indicate that long-term exposure can cause liver disease, high blood pressure, brain damage, and damage to the immune system. Some animals developed lung cancer from breathing cadmium, but many did not, leaving the carcinogen status questionable. Nonetheless, the EPA, Department of Health and Human Services, and International Agency for Research on Cancer list cadmium as a suspected or probable human carcinogen. Cadmium exposure also decreased birth rate and increased birth defects in laboratory animals, and young animals experience behavioral and learning problems as well as skeletal malformations.

### REGULATION ON HUMAN EXPOSURE

Federal agencies limit human exposure to cadmium because of these adverse health effects. The EPA sets a drinking water limit at 5 ppb under the Safe Drinking Water Act, and the U.S. Food and Drug Administration (FDA) sets a limit of cadmium in dye at 15 ppm. People who work in industries that specialize in cadmium products have a much higher dosage. The Occupational Safety and Health Administration (OSHA) limits worker exposure to cadmium at 5 micrograms per cubic meter of air for an eight-hour-day, 40-hour workweek.

*See also* INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE; VOLCANOES; ZINC.

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**carbofuran** On July 31, 1998, an entire crew of 34 farm workers in California had to be evaluated and most hospitalized as a result of working in a field that had been sprayed with a mixture of 0.26 percent carbofuran many hours earlier. Incidents like this are not uncommon with exposure to this powerful pesticide. It is the third most toxic field crop pesticide to humans; a quarter teaspoon can be fatal. It is even more dangerous to birds and has been the cause of bird kills throughout the country, killing millions per year. It was for these reasons that carbofuran was designated a Restricted Use Pesticide (RUP) by the U.S. Environmental Protection Agency (EPA) in 1991. Specifically, the granular form looks like seeds to birds and they feed on it. A single granule can kill a small bird, and scavenger birds can be hurt by eating the dead birds. The granular form was banned from all uses for this reason. Carbofuran is also known as Niagara 10242, Furadan 4F or 3G, Brifur, Crisfuran, Chinufur, Curaterr, Yaltox, Pillarfuran, and Kenofuran. All formulations fall into one of two EPA designations: class I, highly toxic, or class II, moderately toxic. As a result of the ban, carbofuran has dropped to number 368 most dangerous pollutant on the 2007 CERCLA List of Priority Substances.

### PROPERTIES, USE, AND PRODUCTION

Carbofuran is a synthetic organic compound that is a broad-spectrum carbamate, insecticide, acaricide, and nematocide. In pure form, carbofuran is a white to light gray crystalline substance with an odor like that of phenol, but its most common forms are granules and liquid; however, the granules have been banned in the United States since 1994. Before 1991, 80 percent of all carbofuran used was in the granular form. It was first available in the United States in 1969 and used in soil and on plants primarily to control beetles and other large insects, aphids, mites, nematodes, and rootworm.

It has been used for a variety of food and other crops but in decreasing applications every year since the bans began. Crops include alfalfa, rice, corn, cotton, tobacco, small grains, and numerous vegetables, fruits, and trees and shrubs. Traditionally, approximately 5 million pounds (2.3 million kg) is used annually in the United States, about 48 percent of which is applied to corn, though in recent years total use has decreased to about 1 million pounds (454,545 kg) per year. In 1994, the granular form was restricted to a maximum of 2,500 pounds (1,136 kg) per year and only for use on spinach seeds, pine seedlings, cucurbits, and bananas. In 1996, application rates and amounts were restricted on alfalfa, cotton, corn, potatoes, soybeans, sugarcane, and sunflowers. California banned the use on corn and sorghum at that time. In 2006, applications to a group of crops, including corn and sorghum, were cancelled, and a four-year phaseout began for several more, including virtually all of the remaining granular applications.

### ENVIRONMENTAL RELEASE AND FATE

As with most pesticides, virtually all that is produced is released as a nonpoint source pollutant. Only at the manufacturing facilities, as the result of improper disposal, or from spills during transport and storage can it be a point source pollutant, a minor occurrence. It is mainly released directly into the soil, where it is moderately persistent depending upon pH, soil type, and moisture. It is broken down by chemical reactions and microbial activity with minor photodecomposition. Removal half-life in natural conditions ranges from 26 to 110 days. Carbofuran is very mobile in silty and sandy loam and silty clay soils, moderately mobile in silty clay loam soils, and slightly mobile in muck (high organics). This high mobility results in leaching and contamination of groundwater. Carbofuran was detected in groundwater in sandy soils in New York and Wisconsin. A recent study of African-American women in urban areas found that 45 percent of them had detectable levels of carbofuran in their blood, an indication that the problem may be much more prevalent. In surface water, carbofuran does not readily evaporate; nor does it settle into sediment. It primarily degrades by pH-dependent chemical reactions, microbial activity, and photolysis. Laboratory experiments showed removal half-lives of one week at pH of 8.0 (alkaline), 8.2 weeks at pH of 7.0 (neutral), and 690 weeks at pH of 6.0 (acidic).

Carbofuran is highly toxic to birds, bees, fish, and aquatic invertebrates on an acute and subacute basis.



It not only affects animals directly but can also damage offspring. It is also highly toxic to mammals on an acute basis. Plants absorb carbofuran through their roots and distribute it throughout the plant, providing another route for ingestion by humans and wildlife.

### HEALTH EFFECTS FROM EXPOSURE

Carbofuran causes very severe health effects through acute exposure because of its powerful toxicity primarily as a cholinesterase inhibitor, but it causes some potential serious long-term effects, as well. Acute exposure primarily affects the central nervous system and produces sweating, dizziness, headache, salivation, weakness, exhaustion, nausea, vomiting, diarrhea, abdominal cramps, labored breathing, blurred vision, muscle twitching, loss of coordination and balance, increased blood pressure, periodic and continuous convulsions, coma, and death from respiratory failure with increasing dosage. It is difficult to conduct long-term studies on carbofuran because of its toxic effects; exposed populations do not survive for an extended period. Generally, carbofuran appears to affect the central nervous system and has weak effects on the reproductive and immune systems. Reproductive effects include reduced fertility, low birth weight, and increased skeletal deformities in offspring of laboratory animals exposed to low doses. The World Health Organization and all federal agencies consider carbofuran to be noncarcinogenic, but in a recent study, the lung cancer risk for people with long-term exposure appeared to be three times as that for nonexposed people. In two studies an increase in cancer in mice was linked to carbofuran exposure. The case, however, is very weak.

### REGULATIONS ON HUMAN EXPOSURE

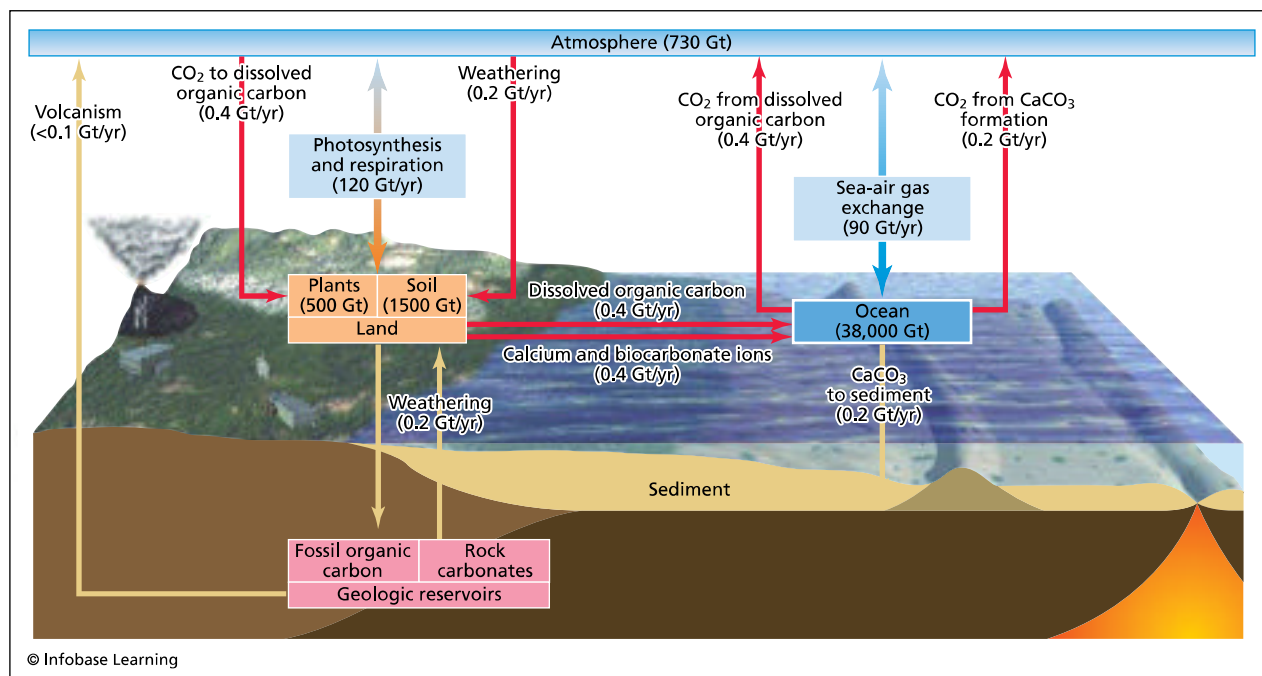
As already described, carbofuran has numerous use restrictions, bans, and other limitations placed on it by federal agencies, but its commercial use and application as a pesticide are also regulated for environmental and human exposure. The EPA limits the amount of carbofuran in drinking water to 40 parts per billion (ppb) under the Safe Drinking Water Act and recommends a maximum of 50 ppb for a single-day exposure for children. The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) of 0.1 milligram in each cubic meter of work area air for an eight-hour day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit (REL) is the same level as for a 10-hour day.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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**carbon dioxide** In 2007, carbon dioxide was declared an air pollutant by the United Nations Intergovernmental Panel on Climate Change (IPCC) and, in 2009, by the U.S. Environmental Protection Agency (EPA). Scientifically, this is an unusual event. Unlike carbon monoxide or other previously designated air pollutants such as lead and ozone, carbon dioxide is necessary for life on Earth. It is inside almost every living organism all of the time; exhaled by all members of the animal kingdom, among others; necessary for photosynthesis, and an essential part of the atmosphere. Without carbon dioxide, the Earth would be in a continual ice age because it traps heat in the atmosphere. This new classification of carbon dioxide as a pollutant applies only to the carbon dioxide produced by human activity and is intended to be a measure of global warming. Separating natural from anthropogenic carbon dioxide in air, however, requires advanced analytical equipment that can separate carbon isotopes, because all carbon dioxide has the same basic properties and is completely mixed in the atmosphere. Reducing total carbon dioxide in the atmosphere, therefore, necessarily involves addressing both natural and anthropogenic sources.



**Block diagram showing the carbon cycle and carbon sinks and sources. The main cycle is the exchange of carbon dioxide with oxygen through respiration and photosynthesis. The other main exchange is between the ocean and atmosphere. Rocks and soils act as sinks, and volcanoes and weathering act as additional inputs.**

Carbon dioxide will soon be regulated under the Clean Air Act and will likely be regulated as a pollutant under federal air quality statutes. According to global measurements made in 2004, carbon dioxide is present in the Earth's atmosphere at a concentration of about 380 ppm. In 1750, at the beginning of the Industrial Revolution, CO<sub>2</sub> levels were estimated (from analysis of ice core samples collected in the Antarctic) to be around 275 ppm. There has, therefore, been a 30 percent increase in more than 250 years, most of it since 1945. This increase is almost completely the result of human activity.

### THE CARBON CYCLE

Under ideal conditions, carbon forms a complex cycling in the environment. In the early atmosphere of the Earth, there was no free oxygen but an abundance of carbon dioxide. The development of photosynthetic bacteria called stromatolites resulted in a change in the chemistry of the atmosphere to include free oxygen. In response, animals evolved to utilize stored energy more efficiently by oxidizing it within their cells. This adaptation of cells from prokaryotic to eukaryotic was the single greatest change in the evolution of life. This began a relationship between producers (mostly plants) and consumers (mostly animals) of oxygen. The basic carbon cycle, therefore, involves the removal

of carbon dioxide from the atmosphere by photosynthetic plants and bacteria to produce oxygen and sugars and the consumption of the sugars and oxygen by animals and bacteria to produce carbon dioxide and water.

Over the years, the producers have been far more effective than the consumers because the atmosphere became as oxygen-rich as chemically possible. Much of the sugars and other stored energy was not consumed but was stored underground in hydrocarbons such as coal and oil. There are orders of magnitude more carbon stored in rocks than in accessible hydrocarbons. Another complicating factor is that the oceans act as a sink for carbon dioxide. They not only contain it in the waters, but also sequester it in deposits called carbonates, primarily limestone.

Humans have increasingly disrupted this cycle. In the clearing of forests to grow crops, large producers of oxygen are replaced by much smaller plants, which do not produce as much oxygen. The filling in and destruction of wetlands, which are very effective in capturing carbon and keeping it out of the air (sequestering agents), significantly slow the removal of carbon dioxide from the atmosphere. The burning of wood and other vegetation converts oxygen to carbon dioxide and prevents sequestration. Production of cement and other industrial chemical processes also consume oxygen and return carbon dioxide to the atmosphere. Pollution of the oceans

with toxic chemicals can poison the marine plants and photosynthetic bacteria, thus potentially further disrupting the removal of carbon dioxide from the atmosphere. Oxidation of metals and other anthropogenic materials at the surface also removes oxygen from the atmosphere.

### NATURAL SOURCES OF CARBON DIOXIDE

Even though carbon dioxide emissions from human sources are currently under public scrutiny, there are even more natural sources. The majority of these natural sources are balanced by the natural sinks of carbon dioxide and are primary components of the carbon cycle.

#### Volcanic Eruptions

The lighter elements of oxygen and carbon, dissolved in the molten rock, are expelled, or out-gassed, during the release of pressure and thermal cooling that occurs during and after a volcanic eruption. It was this type of process that helped form the Earth's early atmosphere. Measurements of ongoing volcanic activity indicate that volcanoes discharge about 145 million–255 million tons (132 million–231 million metric tons) of carbon dioxide annually, which is about 1 percent of the amount released by human activities.

#### Decomposition of Once-Living Organisms

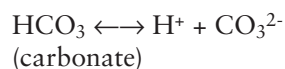
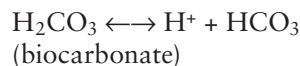
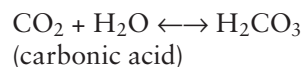
As bacteria break down organic tissue, they consume oxygen, and carbon dioxide is given off as a waste product of cellular respiration. This process is continuous and occurs in all but the most extreme conditions in air and water and on land all over the planet. It even occurs in soils beneath the surface of the Earth. One popular idea to solve the carbon dioxide crisis is to sequester it in living organisms. However, unless the remains of the organisms are protected from this process, it will not work.

#### Respiration

When humans exhale, 0.1 gallon (0.5 L) of air is forced from their lungs. The air they breathe in usually contains 79 percent nitrogen, 21 percent oxygen, about 0.04 percent carbon dioxide, along with traces of other gases (argon and helium, among others) and water vapor. Exhaled air is made up of 79 percent nitrogen, about 16 percent oxygen, about 4 percent carbon dioxide, as well as traces of the other gases and water vapor. The most significant change during breathing is the exchange of about 4 percent oxygen for about 4 percent carbon dioxide. This carbon dioxide is a waste gas generated as oxygen is used to break down sugars and fats for energy.

### Evaporation of Seawater from the Ocean

Enormous amounts of carbon dioxide are stored in the Earth's oceans, with some estimates as high as 93 percent of all the free carbon present on the planet. This occurs as the  $\text{CO}_2$  in the atmosphere diffuses into the ocean and reacts with seawater to form carbonic acid and its related bicarbonate and carbonate by-product ions:



Over geologic time, this diffusion of atmospheric  $\text{CO}_2$  into seawater has resulted in the formation of the limestone, dolomite, and other carbonate rocks present in the crust of the Earth. As described in the carbon cycle, the atmospheric-oceanic  $\text{CO}_2$  diffusion process tends to buffer or stabilize the amount of carbon in the air. Since the reactions are reversible, when atmospheric carbon concentrations decline, higher amounts of  $\text{CO}_2$  are released from the ocean. If atmospheric  $\text{CO}_2$  concentrations increase,  $\text{CO}_2$  will tend to diffuse at a higher rate into ocean water. This process can take hundreds of years, however, as most seawater near the surface quickly becomes saturated with  $\text{CO}_2$  and needs to be mixed with deeper waters before absorbing additional  $\text{CO}_2$ .

### THE GREENHOUSE EFFECT

Even though carbon dioxide in the atmosphere occurs in concentrations less than those of many trace gases (e.g., argon is about 9,000 ppm), it is critically important to our survival, because, unlike argon, neon, and other trace gases, carbon dioxide is not inert and plays a vital role in maintaining the climate of the planet.  $\text{CO}_2$  absorbs infrared radiation, trapping the heat of the Sun in the atmosphere and raising the overall temperature of the Earth very gradually over a long period. This is called the greenhouse effect, and it has been found to occur on other planets in our solar system including Venus, Mars, and even Saturn's largest moon, Titan. Other greenhouse gases present in our atmosphere include water vapor, nitrous oxide, and methane. Other than water vapor, carbon dioxide is by far the most plentiful.

The term *greenhouse effect* was coined by a French mathematician and physicist named Jean-

Baptiste-Joseph Fourier. Born in 1768, he was the son of a tailor; at the age of 16, he became an instructor of mathematics at a prestigious military school in Auxere, France. Although he had an interesting history with his relationship with Napoléon Bonaparte, his most famous work was as chair of analysis at the Ecole Polytechnique in Paris. Fourier is best known for his work demonstrating how the conduction of heat in solid bodies can be analyzed in terms of infinite mathematical sequences, now called Fourier series. The equations developed by Fourier allowed enormous breakthroughs in the fields of heat flow and acoustics. One of his most important works was published in 1822 and entitled *The Analytic Theory of Heat*. In it he describes *l'effet de serre* (literally, “glasshouse effect”), today called the greenhouse effect.

In a steady-state system, as temperatures rise because of increased CO<sub>2</sub> in the atmosphere, additional plant growth will occur and CO<sub>2</sub> will be removed at increased rates for use in photosynthesis. Also, diffusion of carbon dioxide into the ocean will increase, and this too will act to remove excess CO<sub>2</sub> from the atmosphere. As CO<sub>2</sub> is removed, temperatures fall, plant activity slows, and diffusion of CO<sub>2</sub> from the oceans into the atmosphere increases. This would allow carbon dioxide levels to increase gradually and global temperatures to begin, once again, to rise. Eventually, a balance would be reached.

Many scientists believe that human activities, most importantly the burning of fossil fuels, coupled with developmentally driven deforestation, especially in the rain forests of Central and South America, may be overwhelming these naturally occurring carbon dioxide control mechanisms. The combination of increased CO<sub>2</sub> emissions from fossil fuel usage and reduction of plant growth could allow CO<sub>2</sub> levels to increase to catastrophic levels. This scenario is documented by the increase in CO<sub>2</sub> levels, and, since 1950 alone, the average surface temperature of the Earth has increased by 0.7°F, or 0.4°C. There is still some, albeit decreasing, controversy regarding the extent of the enhanced, or anthropogenic, greenhouse effect.

Opponents of the enhanced greenhouse effect idea maintain that the Earth has been warming since the last glacial maximum some 18,000 years ago and that there is a periodicity, or natural cycle, of long-term global heating and cooling. In addition, while accumulation of carbon dioxide may be a contributing factor to global warming, the real mechanisms are nonanthropogenic, including increased cosmic ray activity, variations in volcanic activity, variations in intensity of solar radiation, distance between Earth and Sun, or other causes. Credible scientific data supporting an enhanced greenhouse

effect are starting to become difficult to reconcile with these opinions. In 1995, the United Nations Intergovernmental Panel on Climate Change (IPCC) stated, “The balance of evidence suggests a discernible human influence on global climate.” In 2001, the IPCC issued a second, even more definitive statement: “There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.”

Supporting this finding was an independent report published later that same year by the U.S. National Academy of Sciences (NAS). The NAS reached a similar conclusion but also indicated that natural sources are a likely contributor to the problem:

Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes are also a reflection of natural variability.

As the temperature of the Earth rises, significant changes to global climate are likely to occur. And, since much of human activity is dependent on climate, these changes can result in major disruptions to the worldwide economy, agriculture, and sustainability of our communities.

## IMPACTS OF THE GREENHOUSE EFFECT

### Agriculture

Impacts of global warming on agriculture have been hotly debated, with some researchers stating that a warmer climate will provide an overall beneficial effect, while others make the case for a farming catastrophe. Agriculture in the northern United States and Canada could benefit from warmer temperatures, while agriculture in the southern United States could be harmed as summer temperatures rise and increase the need for additional irrigation. In countries with less developed and more fragile agricultural systems, the effects could be ruinous, as increased rainfall and longer growing seasons will require more active pest management and produce less predictable farming conditions.

### Coastal Resources

Some global warming models predict major rises in sea level as winters become milder and ice sheets melt. If a 20-inch (50-cm) rise in ocean waters were to occur—as, according to some predictive scenarios is possible by the year 2100—more than 5,000



square miles (12,950 km<sup>2</sup>) of coastal land in the world would be submerged. A rising sea level would force major evacuations of densely populated coastlines or extensive public works projects to hold back the rising water, not only in the United States, but also in other countries around the world. There also is evidence that the intensity of major storms may increase with increasing temperature, causing severe coastal damage.

### Energy and Transportation

Warmer temperatures will require additional energy for cooling in some areas and decrease energy usage for heating in others. Although winter transportation may become easier, increased flooding or lower water levels may negatively affect transportation of goods and people by water in some areas, while enhancing it in other areas. Removal of the ice in the Arctic Ocean will certainly improve ship traffic.

### Human Health

The direct effects of global warming on human health are mainly subtle and long-term. Mortality from long-term heat stress and related diseases, especially among the young, elderly, and sick, will probably increase. As precipitation and temperature patterns change, new breeding sites for insects and other pests will develop. There may be a shift in the range and occurrence of infectious diseases, as well. Increased intensity of tropical storms, shifts in food-producing areas and their outputs, availability of freshwater, and other direct effects of global climate change also will affect human health.

### Water

Changes in precipitation patterns, with rainfall increasing in some areas, decreasing in others, would affect the quality and quantity of available drinking water. Also affected would be the availability of water used for irrigation, cooling, electrical generation, and other industrial applications. Increased evaporation may change local water chemistries, increasing salt content with increased rainfall, causing more frequent flooding and erosion.

### Ecology

For global ecosystems, increases in Earth's temperature and the related variations to local climates also have several significant impacts, including affecting the ranges, numbers, metabolisms, and behavior of a variety of plants and animals. Ecological timing or interaction of species plays a key role in the health of an ecosystem. Plants flower, for example, when insects are most available to assist in pollination. If the diverse species of an ecosystem respond to

increasing temperatures in different ways, then the carefully balanced, fragile biology of an ecosystem will be endangered.

The geographic spread or occurrence (ranges) of certain sensitive plants and animals has shifted already in some cases. Many southern and lower-elevation populations have begun to move northward and upward, as they find temperatures warmer and more hospitable. One of the most obvious examples is the range of the North American red fox. As temperatures warm, its range has increased northward to the point where it may soon overwhelm the habitat of its close cousin, the arctic fox. Other instances of range shifts, particularly in the United States, have been well documented for plants, birds, mammals, and intertidal invertebrates. Such shifts can alter vital competitive and predator/prey interactions. This results in a reduction of local or even regional biodiversity.

Ecological impacts of increased carbon dioxide levels, however, cannot be evaluated as a stand-alone issue. There are numerous other stresses currently threatening important habitats and species. Loss of access to undeveloped land due to construction, appearance of invasive species, and impacts related to industrial development, such as soil and water contamination, are likely to cause further stress on species range and diversity as well as associated ecosystems.

## CONTROL OF CO<sub>2</sub> EMISSIONS

Unlike for many of the other air pollutants, there is no simple solution to the emission of carbon dioxide from the combustion of fossil fuels. Humans are extremely dependent on fossil fuels, and they produce enormous quantities of CO<sub>2</sub> when they burn them. Exhaust gas concentrations of other common pollutants such as SO<sub>x</sub> or NO<sub>x</sub>, which have to be controlled, are in the parts per million range, which is small and more easily managed. As fossil fuels are burned, however, carbon combines with oxygen to form carbon dioxide. Since oxygen adds mass, the carbon dioxide weighs more than the original, unburned fuel. For example, on a unit per unit of energy basis, coal emits the most carbon dioxide when burned, about three pounds (1.36 kg) for every one pound (2.2 kg) of coal used. Liquid petroleum fuel (LPF, gasoline and diesel, for example) emits less CO<sub>2</sub> than coal, but quite a bit, about 2.75 pounds (1.25 kg) of carbon dioxide per pound (2.2 kg) of LPG. Natural gas emits the least of the fossil fuels, about 1.35 pounds (0.6 kg) of CO<sub>2</sub> per pound (2.2 kg) of natural gas. In real terms, this means that each tank of gasoline will release about 400 pounds (181 kg) of carbon dioxide. There are more than 600

million motor vehicles in the world today, and, if present trends continue, the number of cars on Earth will double in the next 30 years.

In 2009, total U.S. greenhouse gas emissions were 6 billion tons (5.4 billion metric tons) of carbon dioxide, which is about 19 percent of the global emission load of 29 billion tons (26 billion metric tons). The primary sources of U.S. anthropogenic greenhouse gas emissions were from the generation of electricity and transportation, which accounted for more than 70 percent of total carbon dioxide releases. The use of coal in the United States to generate electricity accounts for approximately 40 percent of the total anthropogenic carbon dioxide released into the atmosphere on an annual basis, about 2.5 billion tons (2.2 billion metric tons). Transportation-related discharges of carbon dioxide contribute another 32 percent of the total anthropogenic atmospheric load, some 2.1 billion tons (1.9 billion metric tons).

The only practical way to reduce carbon dioxide emissions is to reduce the amount of fossil fuel burned, either through improving burner efficiency (smaller, less powerful cars) or by using an alternate, non-carbon-based fuel (e.g., geothermal, hydrogen, or nuclear). Currently, neither of these approaches has much popular economic or political support in the United States.

Internationally, several countries have joined to try voluntarily to limit the amount of greenhouse gases, mostly carbon dioxide, that they discharge into the atmosphere. The Kyoto Protocol, also called the Kyoto Protocol to the United Nations Framework Convention on Climate Change, is an international agreement on global warming that was negotiated in Kyoto, Japan, in December 1997. More than 150 countries have signed the agreement. The United States signed the protocol, but the Clinton administration did not submit it for ratification to the U.S. Senate because they knew it would be defeated. It is, therefore, nonbinding. Australia, citing concerns relating to potentially severe economic impacts, did not sign it. Those countries signing the agreement are obligated to reduce their emissions of carbon dioxide along with five other greenhouse gases by 5.2 percent, compared to the baseline year of 1990. Country-specific goals vary from 8 percent reductions for the European Union to 7 percent for the United States, 6 percent for Japan, and 0 percent for Russia. Australia and Iceland are allowed increases of 8 percent and 10 percent, respectively. If emission targets are not met, then financial penalties are imposed on the offending country.

If fully implemented, the Kyoto Protocol may reduce the average increase in global temperature by between 0.04°F and 0.5°F (0.02°C and 0.28°C)

by the year 2050. If left unchecked, current global temperatures may rise 2.7–9.8°F (1.4–5.8°C) by that time. Although it is a significant first step, many environmentalists are critical of the agreement, asserting that it is not stringent enough, and that without the participation of the United States and other developing countries (such as China and those in Africa and South America), its value is questionable.

For the United States, agreeing to limit carbon dioxide emissions is a difficult decision, as it may limit future economic growth. It would mean, for example, that power plants may not be able to generate significant amounts of new electricity. It also may force the closing of older, coal-fired generating plants, which produce about half of the nation's electricity. This would increase dependence on natural gas, which is already becoming more difficult to find, and imports of foreign oil. Higher costs to both consumers and business would be the end result.

Although leadership at the federal level for control of carbon dioxide emissions is weak, action is being taken at the local level. In November 2004, nine northeastern states—Maine, Massachusetts, New Hampshire, Vermont, Rhode Island, Connecticut, New York, New Jersey, and Delaware—formed the Regional Greenhouse Gas Initiative. This program is a state-level CO<sub>2</sub> emissions capping and trading organization. Almost 20 large American cities have voluntarily agreed to comply with Kyoto Protocol greenhouse gas emission limits. These types of grassroots commitments may be successful at pressuring the federal government to focus on the need to reduce carbon dioxide emissions.

See also CARBON MONOXIDE; GLOBAL WARMING; GORE, AL; REVELLE, ROGER RANDALL DOUGAN; VOLCANOES.

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**carbon monoxide** It is estimated that between 1979 and 1988, there were 56,133 deaths in the United States as the result of carbon monoxide poisoning, classifying it among the most dangerous environmental hazards. Of these deaths, 25,889 are regarded as suicides, making carbon monoxide among the most popular choices for suicide. Some 11,547 deaths were unintentional, 6,552 (57 percent) from motor vehicle exhaust, 83 percent of which were not moving. Poisoning through smoke from house fires was responsible for 15,523 of the deaths. Even today with extensive efforts of education and awareness, unintentional carbon monoxide poisoning still claims up to 500 lives per year and sends between 15,000 and 40,000 people to the hospital per year. Another 2,000 die from suicide. Carbon monoxide is also known as CO (its chemical formula), coal gas, coal fumes, wood gas, mine damp, white damp, and carbon oxide. It is the properties of this extremely common gas and its interaction with blood through respiration that make it so dangerous. Most people across the globe are exposed to carbon monoxide every day, and many are sickened and die as a result. Carbon monoxide is ranked number 189 of the top 275 most dangerous pollutants on the 2007 CERCLA Priority List of Hazardous Substances as a result of this threat to public health.

### PROPERTIES, SOURCES, AND USE

Carbon monoxide is a colorless and odorless toxic gas that is slightly lighter than air. It is also highly flammable. It is the result of incomplete burning of any kind of fuel in an oxygen-poor environment. Exhaust from motor vehicle traffic is the most common source of carbon monoxide, making up 56 percent overall and up to 85–95 percent in urban areas. The second major sources are stationary engines and nonroad vehicles, including construction equipment, airplanes, and boats, which contribute 22 percent of the carbon monoxide budget. Fuel combustion in furnaces, woodstoves, gas stoves, kerosene space heaters, and fireplaces makes up 6 percent. Industrial processes such as metal smelting and processing and chemical manufacturing contribute 4 percent. The remaining 12 percent is from miscellaneous sources, such as tobacco smoke, house fires, forest fires, outdoor grilling, incinerators, and certain

organic chemicals including carbon tetrachloride. It is estimated that annual global emission of carbon monoxide totals 3 billion tons (2.6 billion metric tons), 60 percent from human activities and 40 percent from natural sources.

Carbon monoxide was first mentioned, in the third century B.C.E., in ancient Greece, where coal fumes were said to cause extreme sinus pressure (heavy head), disorientation, and death. The first chemical distillation and isolation of pure carbon monoxide and the first complete description of coal gas poisoning were in 1775–76. The identification of carbon monoxide as the toxic substance in coal gas, however, was not made until 1800. Despite knowledge about its toxicity, carbon monoxide poisoning ran rampant for many years, especially through the use of illuminating gas. In 1927, for example, 611 people died in New York City alone of carbon monoxide poisoning. Edgar Allan Poe is believed by some to have suffered from chronic carbon monoxide poisoning from illuminating gas. One report suggests that haunted house reports may actually have been the result of hallucinations and impact on hearing by chronic carbon monoxide poisoning. Such reports flourished during the 19th and 20th centuries when coal furnaces and illuminating gas resulted, in general, in increased carbon monoxide in indoor air.

Carbon monoxide is also an industrial gas with widespread uses, primarily in chemical manufacturing. It is used in the production of aldehydes, some detergents, methanol, acetic acid, and metal carbonyl complexes. It is also used to treat fresh meat and fish. By combining with hemoglobin and other substances, it prevents oxidation and keeps meats red, an appearance that consumers typically associate with freshness, although not always accurately. Carbon monoxide also has medical applications. Formerly, it was used as a fuel because it is flammable and as a poison for executions.

### ENVIRONMENTAL RELEASE AND FATE

Global background levels of carbon monoxide are between 0.05 and 0.12 part per million (ppm). There was a 1–2 percent increase per year in these levels during the 1980s, but a sharp decline beginning in 1989–92 continues today. In many cities, the average level of carbon monoxide in the air is 17 ppm, with spikes to 53 ppm. Carbon monoxide levels in motor vehicles are typically two to five times as high as in ambient outdoor air. Indoor ice skating rinks can have levels of 148–354 ppm as the result of exhaust from the resurfacers. Similarly, tunnels can have 65–165 ppm. Other areas of danger are kitch-

ens with gas stoves, household utility rooms with gas dryers and water heaters, and parking garages. The concentrated sources and limited circulation of these areas can drive carbon monoxide levels to more than 100 ppm on a regular basis. Environmental tobacco smoke can increase concentrations 20–40 ppm in rooms for periods of up to eight hours after smoking has ceased.

### HEALTH EFFECTS FROM EXPOSURE

Carbon monoxide is inhaled into the lungs, where it is respired into the bloodstream. It chemically attaches (bonds) to the hemoglobin in place of oxygen. These bonds are much stronger than oxygen bonds (up to 200 times as strong) and produce a compound called carboxyglobin (COHb). This process deprives the organs and muscles of needed oxygen. Exposure to carbon monoxide produces both immediate and slowly developing adverse health effects, some of which do not dissipate quickly. Acute exposure produces several flulike symptoms even at concentrations of 5 percent or less, including headache, dizziness, muscle weakness, fatigue, nausea, vomiting, chest pain, confusion, and, at very high levels (40 percent or more), hallucinations, unconsciousness, coma, and death. Death typically arrives by cardiac arrest and may be preceded by electrocardiographic changes, arrhythmias, and pulmonary edema. Long-term chronic exposure can lead to a serious condition called carbon monoxide poisoning syndrome. Symptoms of this syndrome include all of those from acute exposure, including headache, nausea, vomiting, chronic fatigue, dizziness, hallucinations, and vertigo. Other symptoms depend upon the level of exposure; they include muscle and joint pain, tingling and numbness, muscle weakness, memory loss, inability to concentrate, slowed thinking, apathy, irritability, lack of coordination, depression, anxiety, sleep disturbance, personality changes (psychosis, schizophrenia), vision and hearing problems, eating disorders, hypersensitivity to chemicals, aphasia, and seizures. Several of these symptoms, especially those of a psychological nature, may begin two to 28 days after poisoning has ended and last for long periods or even become permanent depending upon the degree of poisoning and the sensitivity of the individual.

If pregnant women experience carbon monoxide poisoning even at relatively low concentrations, there can be severe damage to the fetus. Typically, there is an increase in stillbirths, spontaneous abortion, premature birth, and early postnatal death. If the baby survives, common effects are low birth weight, brain damage, cleft palate and lip, malformation of the mouth, low-set ears, birth defects in

the legs and arms and external genitalia, a number of heart defects, Down Syndrome features, limited to no reflexes, speech problems, cerebral palsy, seizures, visual and auditory impairment, mental retardation, autism, emotional instability, and anxiety.

Certain groups of people are more susceptible to carbon monoxide poisoning than others and have adverse health reactions at lower doses. These groups include unborn babies, infants, and older people who have chronic heart disease, anemia, or respiratory problems. People who suffer from heart-related diseases including angina, clogged arteries, or congestive heart failure may suffer severe chest pain and profound weakness from a single low-level exposure to carbon monoxide. Multiple exposures may cause significant cardiovascular damage. People at high elevations in low-oxygen settings typically react more strongly to carbon monoxide poisoning, as do people who may be environmentally exposed to carbon monoxide, such as cigarette smokers.

### REGULATIONS ON HUMAN EXPOSURE

Many governmental regulatory agencies of the United States and other countries limit exposure of carbon monoxide for workers and the general public. The Occupational Safety and Health Administration (OSHA) has established their permissible exposure limit (PEL) at 50 ppm for an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) recommended exposure limit (REL) is 35 ppm for a 10-hour day and a short-term ceiling (STEL) of 200 ppm. They set the immediately dangerous to life and health (IDLH) designation at 1,200 ppm or more. The National Ambient Air Quality Standards for the United States for carbon monoxide in outdoor air are 9 ppm for eight hours and 35 ppm for one hour. The World Health Organization recommends maximal exposures of 90 ppm for 15 minutes, 50 ppm for 30 minutes, 25 ppm for one hour, and 10 ppm for eight hours. Probably the most effective regulations of carbon monoxide exposure are those that require detectors in offices and residences. In many areas, houses may not be given a certificate of occupancy without a working carbon dioxide detector. Air pollution devices that are now required on all automobiles substantially reduce emissions, eliminating up to 99 percent of CO from exhaust gases in new cars. The required gasoline additive methyl tert-butyl ether (MTBE) was found to reduce carbon monoxide by 40 percent.

*See also* AIR POLLUTION; CARBON DIOXIDE; CARBON TETRACHLORIDE; INDOOR AIR POLLUTION; MTBE; TOBACCO SMOKE.



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**carbon tetrachloride** Carbon tetrachloride is a synthesized organic compound with extensive but declining industrial applications. It has been used as a cleanser for machines and electrical equipment, as a solvent for rubber cement, in the production of nylon as well as other chlorination procedures in organic compounds, as a gasoline additive, for etching of aluminum integrated circuit boards, in the manufacture of pharmaceuticals, as an ingredient of insecticides, and in the production of oils, fats, perfumes, soap, lacquers, varnishes, rubber, wax, and resins, among other products. It also forms impact-sensitive explosive mixtures with certain metal particulates and halogen compounds. Previously, it was a major component in dry-cleaning agents and fire extinguishers, but concerns over its effect on public health limited its use. The main reason for the decline in its usage, however, is that it is the primary chemical in the production of chlorofluorocarbon (CFC) propellants and refrigerants. These compounds have been shown to be the major cause of the deterioration of the ozone layer at the North and South Poles, and, as a result, their production and use have been strongly curtailed. As a result of the direct adverse health effects, the effects on stratospheric ozone, and its very wide distribution, carbon tetrachloride was rated the 47th most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

**PROPERTIES AND PRODUCTION**

Carbon tetrachloride is a heavy, clear organic liquid with a chloroformlike sweet smell and the ability to evaporate very quickly. It is classified as a volatile organic compound (VOC). It was put into produc-

tion in 1907 and immediately used in numerous chemical applications. Some of the trade names and synonyms of carbon tetrachloride chemicals include perchloromethane, methane tetrachloride, Benzinoform, Univerm, Nectorina, Faciolin, Flukoids, R 10 (refrigerant), Tetraform, Tetrasol, Halon 104, and Freon 10, 11, and 12. Domestic production and importation have varied over the years, with peak U.S. production in 1974. Its use was severely restricted in the mid- to late 1970s because of environmental concerns, but, in 1987, some 672 million pounds (305 million kg) was produced and 111 million pounds (50.5 million kg) imported. Domestic production increased in 1989 to 761 million pounds (346 million kg) but decreased to 315 million pounds (143 million kg) by 1991 and 110 million pounds (50 million kg) by 1997 with no imports by 2000. Use of carbon tetrachloride is anticipated to continue to decrease by 7.9 percent per year as it is phased out.

**ENVIRONMENTAL RELEASE AND FATE**

Carbon tetrachloride occurs in at least 430 of the first 1,662 EPA Superfund sites on the National Priorities List. From 1987 to 1993, nearly 76,000 pounds (34,550 kg) of carbon tetrachloride was released into the environment from industrial sources. In decreasing order, the top five states producing the most carbon tetrachloride were Texas, West Virginia, Louisiana, Alabama, and California, primarily from the chlorine and alkalis industry with far lesser amounts from the inorganic chemicals industry, petroleum refining, organic chemicals industry, and agricultural industry. Carbon tetrachloride is released primarily into the atmosphere from industrial sources. Even if discharged into water or on land, it is so volatile that much evaporates into the atmosphere. It is extremely stable in the troposphere, with a residence time of 30–50 years, and, therefore, even though production has been reduced, the volume will continue to increase for several more years. The primary release of carbon tetrachloride from the troposphere is slowly into the stratosphere, where it photolyzes and dissociates ozone.

Carbon tetrachloride enters the surface water system from such sources as industrial spills, wastewater from metal manufacturing industry, agricultural runoff, washing out of the atmosphere through precipitation, and petroleum refining. It is primarily a point source pollutant. At the surface, it quickly evaporates, and this is by far the major way it is removed from the environment. Some bacterial biodegradation also occurs deeper in the water. Carbon tetrachloride is introduced into soil by industrial spills, agricultural runoff, leaching from landfills,

and dumping. Once in the soil, much carbon tetrachloride simply evaporates, while most of the remaining carbon tetrachloride, being highly mobile, moves quickly into the groundwater system because of its poor adsorption into soil and sediment.

### HEALTH EFFECTS FROM EXPOSURE

There are several adverse health effects from exposure to carbon tetrachloride, which were the primary reason for its initial decrease in production. Acute short-term exposure through inhalation or ingestion affects the central nervous system, producing headache, dizziness, vertigo, depression, confusion, loss of coordination, and, in very high doses, respiratory failure, coma, and possible death. The gastrointestinal tract is also affected; nausea, abdominal pain and cramping, and diarrhea result. After the acute symptoms subside, liver and kidney damage may appear. Typically, inhalation exposure to 1,000 parts per million (ppm) of carbon tetrachloride over a few minutes to an hour will cause narcotic effects in everyone, but people vary greatly in their response. Alcohol greatly increases the effects of carbon tetrachloride to the point where an alcoholic is in jeopardy of losing his or her life after only 15 minutes of a 250-ppm exposure. Long-term chronic exposure to carbon tetrachloride can result in additional adverse health effects. Even doses as low as 10 ppm for extended periods can cause liver and kidney damage, and lung damage has been reported in animals as a secondary effect of the kidney damage. Long-term exposure also causes damage to the eyes, with doses as low as 6.4 ppm for one hour per day for an average of 7.7 years. These effects include reduced sensitivity of the cornea, changes in perception of color, changes in the visual field, and inability to adapt to dark areas. Reproductive effects of exposure to carbon tetrachloride have been found in studies of rats. Mothers and fetuses showed marked effects of toxicity and increased resorption of fetuses, and male rats showed testicular degeneration. Rats also developed liver and related cancers, as did mice and hamsters after long-term exposure. On the basis of the development of cancers in rats, carbon tetrachloride is considered a probable human carcinogen.

### REGULATIONS ON HUMAN EXPOSURE

As a result of these adverse health effects, several federal agencies restrict human exposure to carbon tetrachloride. The U.S. Environmental Protection Agency (EPA) has set a recommended maximal contaminant limit (MCL) of five parts per billion (ppb) of carbon tetrachloride for drinking water. They further require the reporting and investigation of any spill of 10

pounds (4.54 kg) or more. The Occupational Safety and Health Administration (OSHA) set an exposure limit of 10 ppm in work area air for an eight-hour workday, 40-hour workweek. For peak exposure, the limit is 200 ppm for five minutes in any four-hour period. The National Institute of Occupational Safety and Health (NIOSH) recommends a short-term exposure limit (STEL) of 2 ppm for 60 minutes and an immediately dangerous to life and health (IDLH) exposure level of 200 ppm. OSHA estimates that there may have been as many as 3.4 million workers either directly or indirectly exposed to carbon tetrachloride and that up to 8 million people living within 12.5 miles (20 km) of manufacturing facilities may be exposed to unhealthy levels.

*See also* AIR POLLUTION; ORGANIC POLLUTANTS; OZONE AND CHLOROFLUOROCARBONS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; VOLATILE ORGANIC COMPOUND.

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**Carson, Rachel (Rachel Louise Carson) (1907–1964)** *American Environmentalist, Biologist* Rachel Carson is considered by most environmentalists to be the mother of the American environmental movement by virtue of her battle against pesticides and dichlorodiphenyltrichloroethane (DDT) in particular. It is truly astounding that in a time when women were struggling to be regarded as serious contributors in many fields, this private, unassuming woman could spearhead such a major movement. Against overwhelming odds and

extraordinary efforts of major chemical companies to suppress her work and discredit her both professionally and personally, Carson managed to capture the interest of the American public and even the top level of government. She testified in Congress on the dangers of pesticides, and after President Kennedy read her book *Silent Spring*, he ordered the investigation of all pesticides that Carson had identified as dangerous. Eventually, this pioneering work would lead to the first bans on dangerous chemicals and the formation of the U.S. Environmental Protection Agency (EPA). Although the battle to save the environment is far from over, the fact that a battle is being waged is largely the result of the vision and sacrifices of Rachel Carson.

### BIOGRAPHICAL INFORMATION

Rachel Carson was born on May 27, 1907, in the small town of Springdale in the Allegheny Valley of Pennsylvania. She grew up on a small farm, where her mother instilled in her a love of nature. Even as a child, Rachel showed a talent for writing, publishing her first work, titled “A Battle in the Clouds,” in the *St. Nicholas Literary Magazine* for children at age 10. In 1925, she entered the Pennsylvania College for Women, which would later become Chatham



Rachel Carson displays her book *Silent Spring* in her library in Silver Spring, Maryland, March 1963. (AP Images)

College. She began as an English major but switched to biology and graduated with a bachelor's degree in 1929 magna cum laude. Carson earned a scholarship to continue her studies at Johns Hopkins University in Baltimore, Maryland, where she graduated with a master's degree in zoology in 1932. Her thesis was titled “The Development of the Pronephros during the Embryonic and Early Larval Life of the Catfish.” The pronephros is a temporary kidney that is formed during the development of permanent kidneys. Upon graduation, she taught zoology at the University of Maryland while continuing her research during the summers at the Woods Hole Oceanographic Institution in Cape Cod, Massachusetts.

In 1935, Rachel Carson accepted a part-time position at the U.S. Bureau of Fisheries, where she wrote science scripts for a radio show called *Romance under the Waters* and supplemented her income by writing articles on natural history for the *Baltimore Sun*. This part-time position led to a full-time position as junior aquatic biologist in 1936, when she became the first woman to take and pass the civil service exam. Over the next 15 years, Carson would rise through the ranks of the successor organization, the U.S. Fish and Wildlife Service, to become the chief editor for all its publications. During this short career, Rachel Carson wrote several books, the income from which allowed her to retire, in 1952, at age 45 to devote herself completely to writing. She bought land on the Sheepscot River near West Southport, Maine, and built a cottage for writing but also kept a residence in Silver Spring, Maryland.

Rachel Carson's life was fraught with personal tragedy. These tragedies began in 1931, when her family was forced to give up its farm, in part, because they were affected financially by the Great Depression but also because two large chemical plants were built on each side of the farm, thus reducing the land's value and its agricultural capacity. Then, in 1935, her father died suddenly, leaving Rachel to care for her mother. In 1936, her sister died, leaving two orphaned children whom Carson and her mother would raise. Her niece became ill in 1959 and eventually died, leaving an orphaned son whom Carson adopted. Her mother died, the same year, and Carson was diagnosed with breast cancer. After a long struggle with the illness, Rachel Carson died on April 14, 1964, at her home in Silver Spring, Maryland, at the young age of 56.

### PUBLICATIONS

Considering the great success of her books, it is surprising that Rachel Carson faced so many hurdles to publication. Her first article in a national maga-



zine, titled “Undersea,” was published in *Atlantic Monthly* in 1937. Her first book, *Under the Sea-Wind*, was published in 1941, but, although receiving good reviews from critics, it was largely unnoticed primarily because America’s attention was focused on the onset of World War II. As her concern over the environment grew, her writings then became more geared toward environmental activism. Her work on the origins and geological aspects of the oceans was rejected by 15 magazines, including *National Geographic Magazine* and the *Saturday Evening Post*. Under the title *A Profile of the Sea*, it was finally published by the *New Yorker* as a serialized collection, although parts of it were also published by *Yale Review*, *Science Digest*, and *Nature*. The entire manuscript was then published in 1951 as the book *The Sea around Us*, which sold more than 200,000 copies in hard cover in its first year. It was on the *New York Times* best-seller list within two weeks and remained there for a record 86 weeks, in 39 of which it was in the top position. It later won the John Burroughs Medal and the 1952 National Book Award and was voted Outstanding Book of the Year in the *New York Times* Christmas Poll. As a result of this mark of distinction, Carson was awarded honorary doctoral degrees from Pennsylvania College for Women and Oberlin College. Her first book, *Under the Sea-Wind*, was rereleased and made the *New York Times* best-seller list. Carson’s next book, *The Edge of the Sea*, was released in 1955 and also made the best-seller list. The National Council of Women of the United States named it Outstanding Book of the Year, and it earned her an achievement award from the American Association of University Women. Carson continued to publish articles during this time including “Help Your Child to Wonder,” published in *Woman’s Home Companion* in 1956 and posthumously released as the book *The Sense of Wonder* in 1965. Her environmental activism culminated in 1957–61, when she wrote her final and most famous book, *Silent Spring*. It was first serialized by the *New Yorker* in June 1962 before being published as a book the same year. It made the top of the best-seller list within two weeks and remained on the list for many years.

### **SOCIAL IMPACT OF HER WORK**

In 1992, *Silent Spring* was named the most influential book of the last 50 years by a congressional panel. More recently, it was designated as one of the 25 greatest science books of all time by the editors of *Discover Magazine*. Indeed, it remains in print to this date. In terms of historical importance and

social impact, it has been compared with Harriet Beecher Stowe’s *Uncle Tom’s Cabin* and Charles Darwin’s *On the Origin of Species*. Although her earlier books created a following for Rachel Carson and fervor of environmentalism, it was *Silent Spring* that elevated her to the leader of the movement. The book identified chlorinated hydrocarbons and organophosphates as the most dangerous pesticide pollutants and named specific compounds to be avoided, especially DDT. It also coined the term *ecosystem*, which became an important concept in environmental studies.

If the period 1957–64 had been carefully orchestrated to set the stage for her work on the overuse of pesticides, the timing could not have been better. The death of hundreds of songbirds in Massachusetts as the result of aerial spraying for mosquitoes was reported to Rachel Carson by a friend in 1957. In turn, Carson called it to public attention through the media and her writings. This event was followed by a damaging spraying of a DDT–fuel oil mix over Long Island, New York, poisoning of workers and farmers in several southern states from pesticide use on fire ants, and banning of cranberries for human consumption during Thanksgiving 1959 because of pesticide use. Public furor over these incidents set the stage for the release of *Silent Spring*, and underhanded and ill-planned attempts to discredit Rachel Carson by several major chemical companies served both to canonize Carson and to identify her as the one true leader of the American environmental movement. As a result, her writings were included in the *Congressional Record* and she received an award from Secretary of the Interior Stuart Udall in 1962. President Kennedy ordered his Science Advisory Committee to investigate all of Carson’s claims. When she testified before the U.S. Congress in 1963, Rachel Carson was introduced as the person who began the environmental movement. As a result of *Silent Spring* and her advocacy, more than 40 bills were introduced to regulate pesticide use in numerous states in 1962. Carson would appear on a major nationally broadcast television special to explain the dangers of pesticides on April 3, 1963. Her death in 1964 of breast cancer was believed by many to have resulted from exposure to the chemicals she was trying to protect the public from, essentially turning her into a martyr. With time, most of the pesticides identified by Carson would indeed be banned. Al Gore, one of our most environmentally conscious politicians, recognized Rachel Carson as his inspiration toward environmentalism and the true leader of the environmental movement. *Time* magazine chose Carson as among the most influential thinkers of the 20th century.



### LASTING INFLUENCE

Rachel Carson's breakthrough work led to the creation of the field of environmental science. People's attitudes regarding air and water pollution, once thought the inevitable by-products of commercial growth and prosperity, began to change. Carson's lasting contribution was, in effect, the establishment of an environmental consciousness. The possibility of damaging the environment was not even a concept to the vast majority of Americans before Rachel Carson enlightened the American people and, indeed, people around the world. It was her influence that launched the generations of environmental scientists and advocates that have devoted their life's work to saving the planet. Although there are still numerous dangerous chemicals being produced and released into the environment today, it is a hopeful sign that many have been banned and that the dangerous concentrations once found in human breast milk have now largely been reduced. It is fitting that in 1969, the U.S. Department of the Interior changed the name of the Coastal Maine Refuge to the Rachel Carson National Wildlife Refuge and that, in 1980, President Jimmy Carter posthumously awarded Carson the Presidential Medal of Freedom, but her influence and legacy extend far beyond any medals and accolades, as a true champion of the environment.

See also DDT; ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; GORE, AL; PESTICIDES.

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**Castillo de Bellver oil spill Cape of Good Hope, South Africa August 6, 1983 Water Pollution** Atop a hill on the Spanish island of Majorca, about 120 miles (193 km) off the Valencian coast in the Mediterranean, is a 14th-century castle built for King James II of Majorca. Although James II did not last long as king, the castle built for him and eventually named Castillo de Bellver, or, roughly translated, Castle of the Beautiful View, survives to this

day and is one of the most popular tourist attractions on this beautiful semitropical resort island. Used as a military prison in the 1700s and 1800s, Castillo de Bellver also held loyalist prisoners during the Spanish civil war (1936–39). Although Castillo de Bellver is well known to travel agents and European vacationers, its name among commercial seafarers is more likely to provoke an image of explosions and burning oil slicks than more peaceful thoughts of sunbathing and fine wine.

### BACKGROUND

In early August 1983, the pride of the Spanish-owned Compania Arrendataria del Monopolio de Petroleos (CAMPESA) oil company's fleet of supertankers, the *Castillo de Bellver*, picked up a load of almost 2 million barrels (318 million L) of lightweight crude oil pumped from Persian Gulf fields in Murban, United Arab Emirates, and Upper Zakum, Abu Dhabi. Oil was Spain's major source of energy at this time, although its use had peaked and was now starting to decline as it was gradually being replaced by natural gas after the Organization of Petroleum Exporting Countries (OPEC) embargo of 1973. In 1985, Spain was still importing almost 40 million tons (36 million metric tons) of oil from the Middle East, which provided half of the country's energy.

As the 1,000-foot- (304.8-m-) long *Castillo de Bellver* made its way out of the Persian Gulf, through the Straits of Hormuz, and down the east coast of Africa toward the Cape of Good Hope, all seemed normal. Although not quite at the southern tip of Africa, the Cape of Good Hope, or Cape of Storms, as its discoverer Bartolomeu Dias had named it, became the halfway point for trading ships and merchantmen trying to make their way to the riches of the Middle East. The city that sprang up around the harbor 30 miles (48.3 km) north of the Cape of Good Hope, Cape Town, South Africa, was at one time nicknamed Tavern of the Seas, because this is where ships would put in and reprovision. Today, the South African government has designated the Cape and its environs as the Cape of Good Hope Nature Reserve, part of Cape Peninsula National Park. This area is widely acknowledged as habitat for extensive and diverse fauna and flora, all within a few minutes' drive of a major metropolitan center. More than 3,000 species of plants are concentrated near the tip of this continent, where the Indian and Atlantic Oceans meet. There are sand hoppers and shellfish on the beaches; 250 species of birds, baboons, antelope; and countless other varieties of small game in the reserve.

### THE ACCIDENT AND OIL SPILL

The southern tip of Africa is well known for its violent storms and especially strong winds, brought about as the warmer waters of the Indian Ocean mix with those in the cooler Atlantic. At about 2:00 A.M. on August 6, 1983, when the *Castillo de Bellver* was some 70 miles (112.7 km) west-northwest of Cape Town, it caught fire. The 31 crewmen and two passengers abandoned ship shortly after the fire began and were picked up by a local fishing trawler and a passing container ship. Three crewmen were reported missing and were never found.

The oil in the cargo holds of the *Castillo de Bellver* was a high quality crude, with a low viscosity and high vapor pressure. These physical properties of the oil resulted in its rapid ignition and dispersion into the environment. Within a few hours of the start of the fire, a burning oil slick 300 yards (274.3 m) long trailed the ship as it drifted on the currents. Smoke from the fire rose 1,000 feet (304.8 m) into the air, and farmers and ranchers later would report a “black rain” of oil droplets and soot deposited on their vineyards, wheat fields, and livestock. Salvage vessels that tried to fight the fire had to stay more than 1,000 feet (304.8 m) away because of the intense heat and flames. At around 10:00 A.M., the last of the structural members holding the ship together failed under the intense heat, and the *Castillo de Bellver* broke in two. The stern section turned over and quickly plunged 1,400 feet (426.7 m) to the ocean bottom, taking with it between 15,000 and 40,000 tons (13,608 to 36,287 metric tons) of oil.

Strong, eastward-blowing winds began to push the still-burning and leaking forward section of the *Castillo de Bellver* toward the coast, directly into Saldanha Bay and Langebaan Lagoon, a marine and wildlife sanctuary and one of the most ecologically sensitive areas of the Cape Peninsula National Park. This area of the South African coast also is an important commercial fishery, supplying more than 50 percent of the region’s rock lobster and surface, middepth, and bottom-dwelling fish and serving as a major spawning ground and nursery for those species.

By the next morning, an oil slick 20 miles (32.2 km) long and three miles (4.8 km) wide had formed, and South African officials began to fear that an ecological disaster was about to occur. LANDSAT satellite data were being used to track the slick and predict its landfall. Fortunately, two days after the spill, just as the leaking wreck and oil slick was about to make landfall on the South African coastline, the unpredictable weather of this area, just a few hundred miles north of Antarctica, changed. Winds, which had been blowing from the west-



Bellver Castle in Palma de Majorca, Spain (JCVStock; used under license from Shutterstock)

southwest and toward the shore, shifted and started to blow from the north and northwest at a steady speed of seven knots. Combined with the seaward flowing Benguela Current, the wind began to push the oil and still-burning and leaking bow section of the *Castillo de Bellver* back out to sea.

By August 7, the fire had mostly burned itself out and a tugboat was able to secure a line onto the bow section of the wrecked Spanish supertanker and drag her farther out to sea, well away from ecologically sensitive shoreline areas. After receiving permission from the ship’s owners, on August 13, South African demolition experts attached explosives to the bow section in two places and blew holes in the last floating section of the hull. The remains of the *Castillo de Bellver* sank in more than 10,000 feet (3.1 km) of water along with a cargo of an estimated 100,000 tons (90,719 metric tons) of oil. Of the 60,000 tons (54,431 metric tons) or so that are thought to have been released, 10 percent probably burned off, 40 percent evaporated, and the rest was dispersed through natural wave action or by the 60,000 gallons (234,000 L) of chemical dispersants sprayed on the landward side of the slick from aircraft and spill response vessels.

Heavy rains that had begun shortly after the fire washed the oil and soot that had blown inland off most fields. Crop damage was reported as minimal. Onshore, the most obvious impact from the spill was the oil covering about 1,500 gannets, but the majority of these were captured and released after cleaning.

### THE AFTERMATH

The large quantity of oil that had sunk with the ship, especially when the stern went down 25 miles (40.2 km) off the coast, led to a series of studies that

were conducted over the next few years to assess potential ecological impacts. At that time, it was thought that the great pressures and cold temperatures present on the seafloor would tend to solidify or immobilize the oil, although the stern section of the *Castillo de Bellver* reportedly continued to leak small amounts of petroleum for another six months. The South African government had several concerns: that the dispersed oil could have settled on the seafloor and contaminated benthic (bottom-dwelling) fauna, including fish, or fouled trawling nets, and that the area where the oil was released might have contaminated spawning grounds and caused widespread damage to fish eggs, plankton, and larvae.

Sampling surveys of water, plankton, and sediment were performed in areas where the oil slick was heaviest, where the dispersants had been applied most aggressively, and adjacent to the sunken, oil-laden stern section of the *Castillo de Bellver*. Analytical data indicated that hydrocarbon values in all three media, water, plankton, and sediment, as well as later sampling of fish eggs and larvae were within background levels. Researchers also confirmed that oil leaking from the sunken stern section of the *Castillo de Bellver* was being dispersed rapidly in the water column without observable ecological impacts.

The lack of significant ecological damage by the *Castillo de Bellver* spill was due more to good luck than to good planning. If the wind had not changed direction when it did, then it is likely that this spill, similar in size to that of the *Amoco Cadiz*, which broke apart off the French coast in 1978, would have been much more ecologically devastating and just as economically ruinous.

See also AMOCO CADIZ OIL SPILL; BEACHES; CONTINENTAL SHELF; OIL SPILLS.

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#### Chemical Control Corporation Elizabeth, New Jersey April 21, 1980 *Air and Soil Pollution*

The year 1980 was one of transition for the environmental movement in the United States. The U.S. Environmental Protection Agency (EPA) had been founded 10 years earlier, and the programs it had developed to reduce air and water pollution were starting to show results. Political support, however, was beginning to wane because of the short-term economic hardships that some pollution control regulations were having on industry and employment. As a result of overwhelming media focus on the Iranian hostage crisis, even Earth Day was struggling. Only about 3 million activists participated in environmental events around the country, down from 29 million in 1970. A case could be made that the public and its leaders were losing interest in the environment.

Over the next two years, however, a series of environmental catastrophes reenergized both grassroots and national political support for environmental issues. The presence and impacts of facilities that received and processed industrial wastes would emerge in the public consciousness. Places like Love Canal, Valley of the Drums, Times Beach, and Stringfellow would be added to the national lexicon and become synonymous with terror, corruption, disease, and death. This new era began with a fire on a small, two-acre (0.81 ha) parcel of land tucked into a corner of Elizabeth, New Jersey, sandwiched between the Elizabeth River and the Arthur Kill, just a few miles from New York City.

#### BACKGROUND

Between 1970 and 1978, the Chemical Control Corporation (CCC) received a wide variety of wastes intended for processing and/or storage prior to shipment to other waste disposal sites. Two small warehouses and seven chemical storage tanks, or vats, occupied the site, on reclaimed marshland at an elevation just above sea level in this heavily industrialized area of Union County, New Jersey. CCC's owners aggressively marketed their little facility and accepted all types of wastes, including acids, arsenic, bases, cyanides, flammable solvents, polychlorinated biphenyls (PCBs), compressed gases, biological agents, and pesticides. As effective as the owners were at receiving waste, they were far more ineffective at processing it. During its operation, CCC was regularly inspected by the fledgling New Jersey Department of Environmental Protection (NJDEP), which was founded only a decade earlier in 1970.



The facility was cited for numerous violations related to the storage and discharge of materials at the site. Eventually, the situation became so egregious that the state shut down the business, placing it in receivership in January 1979.

For the next 15 months, NJDEP and its contractors worked to stabilize the property. This process entailed draining and disposing of liquids from the seven aboveground storage tanks and identifying and processing about 10,000 of the more than 65,000 full and partially full drums of waste materials that were in the warehouses and stacked haphazardly around the property, sometimes in piles five to six drums high. This occurred before the Superfund program, and the state had to use its own resources to remediate the site as they were available. By the beginning of April 1980, most of the loose (noncontainerized) solids and liquids had been removed, along with a majority of the radioactive waste, highly explosive liquids, and infectious (biological) wastes.

### THE FIRE AND EXPLOSION

At about 11:00 p.m. on April 21, 1980, one day after Earth Day, a fast-moving fire broke out in one of the warehouses on the property, which held more than 20,000 drums full of waste. Its source would never be determined, but arson is suspected. Published newspaper reports and testimony by one of the owners later would claim that individuals associated with organized crime, upset by the state takeover of the property and their associated loss of revenue, started the fire. It would burn for 10 hours, and not only lit up the nearby skyline of downtown Manhattan, but also reignited an interest in the environment that would shape and define the movement for another 10 years. As a result of Chemical Control, 1980 would become known by some as the “Year of Hazardous Waste.”

When emergency crews arrived, they knew this was not a typical fire. Flames were shooting hundreds of feet into the air, and drums filled with noxious chemicals were being launched as if from cannons, exploding like fireworks high above the ground. Firefighters without respiratory protection were quickly overcome by noxious fumes, and their throats started to dry up and ache. Eventually, almost 70 people (most of them firefighters) were hospitalized with problems ranging from difficulty breathing to skin rashes.

At a distance from the fire, thousands of residents of Elizabeth, New Jersey, and Staten Island, New York, awakened by the thunderous explosions, rushed into the night and were shocked to see a

bright glowing of red, green, and yellow, depending upon which chemical was burning. As firefighters struggled to bring the four-alarm blaze under control, officials from NJDEP and the New York Police Emergency Control Board started hastily to assemble evacuation plans for the residents of Elizabeth and nearby Staten Island. Several hundred thousand people were about to be removed from hospitals, nursing homes, apartments, and houses. Luckily, three factors combined to forestall evacuation. Wind direction shifted and started to blow the mushroom-shaped cloud of contaminants that had formed directly above the CCC site to the southeast, away from populated areas and out to sea. Only a few months earlier, NJDEP had removed some of the more dangerous chemicals from the site, including 500 pounds (226.8 kg) of trinitrotoluene (TNT), as well as numerous drums of benzene, picric acid, and radioactive waste. This not only lessened the severity of the fire, but also reduced the toxicity of the smoke and ash emanating from it. Finally, the heat of the



Fire at Chemical Control Corporation drum storage yard, Elizabeth, New Jersey, April 21, 1980 (AP Images)



fire was so intense that it essentially incinerated many chemicals, rendering them much less poisonous than they might have been.

Smoke and ash from the conflagration, however, covered 15 square miles (38.9 km<sup>2</sup>) and forced the closing of schools in Elizabeth, parts of Staten Island, and several other nearby towns. Residents were urged to stay indoors for several days after the fire was extinguished, not to let young children play outdoors, and to wash down cars and lawn furniture to remove potentially contaminated dust and ash.

### THE AFTERMATH

After the fire, cleanup activities at the CCC site accelerated dramatically and became the largest emergency response action ever conducted by NJDEP. Within six months, all the firefighting apparatus was decontaminated and the remaining 49,000 drums were removed, along with more than 250,000 gallons (946,353 L) of liquid chemicals.

Eighteen months after the fire, the containers that had fallen or been launched into the Elizabeth River, both as a result of the fire and during routine site operations, were found and removed. During the operation, drums were stacked three and four high by site operators along the entire length of the riverbank. The warehouses were decontaminated and demolished, and dredging of Elizabeth River sediments, contaminated by runoff from rainwater, as well as during firefighting operations, was completed. It took another five years, however, to collect, test, and dispose of more than 200 fire-charred, unmarked gas cylinders from the site. Storm sewers damaged by heavy equipment during these remedial activities also were replaced, and several were cleaned and sealed to minimize the spread of contaminated runoff into the Arthur Kill. An earthen berm was constructed to isolate the site from the Elizabeth River and a chain link fence installed to reduce the likelihood of unauthorized persons entering the site.

For the next 18 months, NJDEP operated a groundwater remediation system to capture and treat water in the shallow aquifer, which had become highly contaminated with volatile and semivolatile organic compounds, as well as heavy metals. The contaminated soil was an even bigger problem. A variety of organic chemicals, pesticides, acid and base-neutral extractable compounds, and metals had been released during the storage and processing of waste at the site. Leachate from this soil threatened surface water and groundwater quality, as well as posing a risk to the public from airborne dust inhala-

tion and other potential exposure pathways. After reviewing the available alternatives, NJDEP decided to excavate a three-foot (1-m) layer of the most heavily contaminated soil and ship it to a treatment and disposal facility. Another 30,000 tons (27,216 metric tons) of soil was treated on-site by mixing it with a stabilizing agent that would prevent the contaminants from leaching. This soil then was used as on-site fill material and covered with an impermeable cap.

The \$26-million cost for the cleanup was staggering, especially in 1980 dollars. More than 80 percent of this money eventually was recovered from the more than 200 companies that had originally generated the waste, most of which thought they were paying to have it properly disposed of by CCC, a fully permitted and licensed waste processing facility. The final cleanup was completed in 1993, but the EPA continues to monitor the site periodically in order to confirm the effectiveness of the remedial action. The EPA assumed responsibility for the cleanup at the CCC site in late 1981, after NJDEP nominated it for inclusion in the Superfund program (National Priorities List [NPL]). Costs associated with this monitoring are estimated to be about \$60,000 per year for another 30 years. Criminal charges were filed against the owner of CCC, as well as a waste transporter who diverted truckloads of waste to the site, instead of sending them to their intended destinations. Both were found guilty and sentenced to several years in prison.

### LONG-TERM EFFECTS

The Chemical Control disaster had all the ingredients of high drama including a spectacular fire, public officials agonizing over whether to order the evacuation of one of the most densely populated parts of the United States, and mobsters conspiring to defraud millions of dollars from hundreds of companies, then trying to cover up the crime. All of these factors not only kept the Chemical Control incident in the public eye for many years, but also served a more important purpose. The fire and risk to the public at CCC were among the major incentives to force a reluctant Congress finally to act on legislation that established new regulations to control the handling and disposal of hazardous waste, as well as a fund to help states pay for the cleanup of abandoned chemical dumps. This legislation is the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), better known as Superfund.

The CCC incident also helped launch the political career of Jim Florio, a congressman from New

Jersey's First Congressional District. Deeply affected by events in Elizabeth, as well as in Love Canal and other cities facing similar crises across the country, Florio authored and sponsored the CERCLA legislation and then led a tireless fight to make it law. Finally enacted on December 11, 1980, Superfund ushered in a new era of environmental protection and, for the first time, provided a vehicle for the federal government quickly and effectively to respond directly to releases or threatened releases of hazardous substances that endanger public health or the environment. Many states followed the federal government's lead and passed state-level Superfund laws, which complement and in some cases are even more stringent than CERCLA requirements.

See also ARSENIC; BENZENE; CYANIDE; ENVIRONMENTAL PROTECTION AGENCY; (EPA), U.S.; LOVE CANAL; PCBs; PESTICIDES; RADIOACTIVE WASTE; STRINGFELLOW ACID PITS; SUPERFUND SITES; TIMES BEACH SUPERFUND SITE; VALLEY OF THE DRUMS; VOLATILE ORGANIC COMPOUND.

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**Chernobyl nuclear disaster Pripjat, Ukraine April 26, 1986 Air Pollution** The nuclear disaster at Chernobyl may be the most far-reaching and devastating human-caused environmental catastrophe in recorded history. The impacts of Amazonian deforestation and global warming/climate change are still being evaluated and assessed, but there is no doubt about Chernobyl's short- and long-term effects on both public health and the environment. Some 130,000 people were displaced and thousands of square miles of productive farm-

land contaminated. Beyond the 30 deaths directly attributed to the explosion and fire at Chernobyl, the health of some 5 million people has probably been compromised.

#### BACKGROUND

Located at Pripjat, Ukraine, the Chernobyl nuclear power plant was one of the largest and oldest of the Soviet Union's 15 civilian nuclear electric generating plants. It employed some 4,500 workers and was located about 80 miles (128.8 km) north of Kiev, a city with a population of 2 million. In 1986, the town of Pripjat had a population of 45,000, including 16,000 children, and was located five miles (8.1 km) from the nuclear facility. The neat little town was constructed by the Soviet Union in the 1970s with wide tree-lined streets, an amusement park, a community center, and a host of other modern conveniences for the scientists, technicians, and their families who lived there.

Four water-cooled, graphite-moderated reactors (abbreviated in Russian as RBMK, or "high-power, channel-type reactor") operated at the Chernobyl nuclear complex, and a fifth was under construction. The Soviet Union utilized RBMK reactors for a number of reasons. They are relatively inexpensive to build and operate; total plant size can be increased in modular increments as the demand for power rises; and they were able to use recycled fuel from Soviet military reactors. The RBMK reactors also had disadvantages. They tended to be unstable, susceptible to large power surges unless water coolant levels were carefully controlled. Also the more than 3,000 fuel rods used to power the reactor were not within a reinforced containment-type structure, but rather surrounded by a graphite moderator or honeycomb through which coolant flowed. Graphite has such a high heat capacity and melts at such extremely elevated temperatures that a containment building was not considered necessary. As long as the temperature of the heat produced by the fission of the uranium fuel is low and of short duration, this type of reactor can withstand an interruption in the flow of coolant. Several Western countries, including the United States, had small RBMK-type reactors being used for research purposes, but none was licensed for commercial power production.

The Soviets had designed and installed several safety features on the Chernobyl reactors. A sealed metal structure filled with inert gases surrounded each RBMK reactor to help keep oxygen away from the 1,300°F (704.4°C) graphite moderator, and extensive amounts of shielding protected plant operators from the intense radiation given off during fission.

This shielding included a concrete slab upon which the reactor rested, a sand and concrete barrier on each side of the reactor, and a large steel-reinforced concrete slab on top of the reactor. Control rods also were in use. A control rod is a solid metal bar commonly made of neutron-absorbing metals such as silver, boron, or cadmium. When removed or inserted into the reactor core, they either increase or decrease the number of neutrons being emitted by the fissionable fuel, which, in turn, changes the rate or speed of the nuclear decay process. With the control rods removed, more neutrons can bombard the fuel, more fission occurs, and more heat and steam or power is produced. Modern reactors have the control rods suspended above the core by electromagnets. If a power failure occurs, the rods automatically drop and cause a shut in a process known as a scram. This term originally was an acronym for *safety control rod ax man*. In early reactors, the control rods hung above the core suspended by a rope. In an emergency, a technician would cut the rope, and the rods would fall into the reactor and stop the fission process.

### THE ACCIDENT AND RELEASE

Some uncertainty remains as to the sequence of events that led to the disaster. It is generally agreed, however, that on April 26, 1986, at about 1:20 A.M. of the first warm, sunny Sunday of spring, reactor no. 4, which had gone online in 1983, began to reduce power in preparation for a routine operations test. The test would indicate to engineers how long the turbine and generators could run if, in some sort of emergency, the reactor shut down. For some reason, the operators turned off the reactor's primary and secondary emergency water-cooling systems. Then the power and automatic reactor shutdown systems were disconnected. Also, only about six control rods were in place, rather than the 30 required by the test procedure. This test configuration was in violation of numerous plant operational safety protocols. The Chernobyl station reportedly had a long history of plant mismanagement, poor training, and, more recently, labor unrest.

During the test, an operator's error may have caused the reactor's output to drop below a stable level, resulting in an enormous power surge. As the temperatures in the reactor increased, the fuel rods melted and burst or exploded. Realizing that the reactor was overheating, the operators activated the cooling water system. When the water had contact with the superhot melting fuel rods, a second explosion occurred, blowing the 1,000-ton (907.2-metric ton) steel cover off the reactor. The cover was attached to the fuel rods, and, once exposed, they

released fission products into the atmosphere. This explosion also threw fragments of burning fuel and graphite from the core and allowed air to rush in, causing the remaining graphite to ignite. For the next 48 hours, uncontrollable flames shot 1,000 feet (304.8 m) into the air.

It took several days to extinguish the fire and more than 10 days to stop the release of radioactivity. Most of the firefighters were plant workers, who knew that they were facing certain death either quickly in the fire or more slowly by radiation sickness. They, nonetheless, worked frantically to try to control the radiation that was pouring out of the ruined reactor building and raining down on their families and friends in nearby Pripjat. As the extent of the catastrophe became known, the Soviet government began using helicopters to drop boron, dolomite, sand, clay, and lead onto the smoldering core in an effort to limit the release of radioactive particles. It took more than 1,800 sorties and 5,000 tons (4,536 metric tons) of material eventually to stop the worst of the radiation leakage. Thirty people, including the reactor room operators, died almost immediately as a result of the explosion and fire, and, as the radiation levels began to rise, Pripjat was evacuated on May 2. Over the next 10 days, 130,000 people were forcibly relocated from their homes and farms within a 20-mile (32.2-km) radius of the reactor, now called the exclusion zone.

An airborne plume of radiation moved north with the early spring winds and contaminated more than 1 million acres (0.4 million ha) of valuable farmland in Belarus and western Russia. It then swept west across Europe, with elevated levels of radioactive fallout from the accident eventually settling across the entire Northern Hemisphere. Independent studies funded by the United Nations estimated that the amount of radioactivity released was 200 times more than from the Hiroshima and Nagasaki bombs. Millions of people in what is now Belarus, Russia, and Ukraine were exposed to varying amounts of radiation.

### RELIEF AND CLEANUP

On May 23, the Soviet government ordered the distribution of prophylactic iodine. Significant amounts of radioactive iodine were released during the accident and, since the thyroid gland cannot detect the difference between radioactive and nonradioactive iodine, it takes up the radioactive iodine in whatever proportion it is available in the environment. By ingestion of large doses of stable, nonradioactive iodine, the thyroid gland becomes saturated and will only absorb very small amounts of radioactive iodine. The delay





Destroyed reactor at Chernobyl nuclear power plant, Ukraine, April 1986 (AP Images)

in ordering the distribution of stable iodine, however, negated any positive medical effects. The radioactive iodine had already accumulated in the thyroid glands of the exposed populations.

United Nations and foreign government health services, including that of the United States, concluded that 31 people died in the accident. All were plant workers; three died directly from the explosion and 28 from radiation poisoning. More than 500 people were hospitalized, but about 5 million people were exposed to radiation from the plant. Most of the radioactive fuel and graphite was deposited close by as dust and debris, but the lighter material such as iodine 131 (half-life of eight days) and cesium 137 (Cs 137) (half-life of 30 years), which were the main fission products inside the reactor, were carried by winds and distributed more widely. In general, after 10 half-lives, a radioactive substance is considered safe for human contact. For Cs 137, this means it

will be 300 years before unrestricted use of the land can be allowed.

After the fires and worst of the radiation releases were controlled, some 200,000 people (“liquidators”) were mobilized from around the Soviet Union to assist in the cleanup. The number of liquidators working at Chernobyl later increased to more than 600,000. These volunteers, lured to Priypat by the promise of high salaries and special bonuses, worked between 1986 and 1987 to stabilize the now-demolished reactor building. In exchange for the money, they received doses of radiation averaging around 100 millisieverts (mSv). Recent studies estimate that about one in 100 people will develop cancer or leukemia from a dose of 100 mSv. Some 20,000 liquidators received radiation doses of 250 mSv, and a few were exposed to more than 500 mSv.

Within seven months after the explosive release of radioactivity at Chernobyl, an impressive-looking





**Map showing the location of Chernobyl in Ukraine and eastern Europe and the area of high radiation (shaded) from nuclear fallout. Inset map shows location in Europe.**

reinforced concrete sarcophagus was erected around the blasted and ruined structure where reactor no. 4 had once operated. Inside this hastily poured concrete shelter is about 96 percent of the reactor's nuclear fuel—an estimated 180 tons (163.3 metric tons) of uranium with a total radioactivity  $7 \times 10^{17}$  becquerel (Bq). For comparison purposes, a radioisotope (e.g., barium) used for a medical test or diagnosis contains about  $7 \times 10^7$  Bq. More than 20 years after the accident, this sarcophagus still poses great danger because of the radioactivity.

### THE AFTERMATH

The Chernobyl sarcophagus was constructed as an interim measure. It was designed to last around 20–30 years and as such was not constructed well. As a result, the concrete has shifted and cracked, and the reactor building is slowly filling with water from rain and snowmelt. This spreads the contamination internally and increases the risk of a release to groundwater. The high moisture levels also increase the rate of corrosion of main steel support beams. Although some repairs have been made, the structure itself is thought to be so unstable that a heavy windstorm or a small earthquake might cause it to

collapse. Such a catastrophic failure could result in another release of significant amounts of radioactive dust and debris. The Shelter Implementation Plan, funded by many Western countries, as well as Ukraine and Russia, is a joint design and engineering effort intended to develop a replacement for the existing Chernobyl sarcophagus. Preliminary plans call for a new 20,000-ton (17,857-metric ton) structure to cover the old sarcophagus completely. With a design life of at least 100 years, it is planned to be completed in 2012 at a cost of approximately \$1.2 billion.

After the accident, construction was halted on the two unfinished reactors. The three remaining reactors continued to operate, simply because there was no other way to supply Ukraine's electrical power needs. In 1991, fire destroyed reactor no. 2, and in 1996 reactor no. 1 was decommissioned after a deal brokered by the International Atomic Energy Agency (IAEA) to help Ukraine develop alternate energy sources. Operations at reactor no. 3 ended in December 1996.

More than 15,000 jobs were lost as a result of the accident, and it resulted in a \$12.8-billion disruption to the Soviet Union and Ukrainian economies. Some analysts credit Chernobyl as helping to contribute to the collapse of the Soviet Union. More than 6,000 people work on a daily basis at the facility on decommissioning and stabilization activities, and about 1,000 people have returned to live (unofficially) within the exclusion zone.

Studies in the early 1990s by the World Health Organization (WHO) of more than 1 million exposed people living in Ukraine, Russia, and Belarus confirmed a significant increase in thyroid cancer among exposed children. By 1995, the WHO had conclusively established that almost 700 cases of thyroid cancer including 10 deaths among children and adolescents were directly caused by radiation released from Chernobyl. Although no increase in leukemia cases apparently has occurred, the long latency period for this disease makes it likely that it will take a few more years to become statistically discernible. Similarly, there was no increase in congenital birth defects or other adverse pregnancy outcomes attributable to Chernobyl. In the region between northern Finland and the Adriatic Sea, however, miscarriage rates increased dramatically for about two years subsequent to the accident.

*See also* AIR POLLUTION; RADIOACTIVE WASTE.

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**chlordanne** Although the powerful insecticide chlordanne has been banned since April 14, 1988, from all uses except the treatment of fire ants in electrical transformers, it is estimated that more than 50 million Americans are exposed to it on a daily basis and most others on a regular basis. Chlordanne is one of the most persistent organic chemicals in the environment. It can remain in the atmosphere so long that it has been found all over the Pacific and Atlantic Oceans and even in the Arctic. The reason that so many Americans are directly exposed to it is that it was still permitted to be used for residential termite control even after the first ban on July 1, 1983, when all of its other applications were terminated. It was used in most homes from southern New England to California and primarily in the South built before 1988 in areas having or in danger of having termite problems. Chlordanne is also known as Velsicol 1068, Asponchlordanne, Belt, Chloridan, Chlor-kil, Cortilan-Neu, Dowchlor, Oktachlor, Oktaterr, Synchlor, Tat Chlor 4, Topichlor, Toxichlor, Intox 8, Gold Crest C-100, Kilex, Kypchlor, Niran, Termi-ded, Prentox, and Pentiklor. It has been identified as a component in 176 of the first 1,350 U.S. Environmental Protection Agency (EPA)-designated Superfund sites (on the National Priority List) in which it was tested. As a result of this widespread distribution and the adverse health effects it produces, chlordanne was ranked number 20 of the 275 most dangerous pollutants on the 2007 CERCLA Priority List of Hazardous Substances.

### PRODUCTION AND USE

Chlordanne is a synthetically created organic chemical, typically distributed as a white powder that turns into a thick colorless to amber liquid with an unpleasant chlorine odor if mixed with water. It also was available as dust, granules, concentrates, and oil solutions. Chlordanne is really a mixture of about

23 different chemicals with about 10 major components including trans-chlordanne, cis-chlordanne, beta-chlordanne, heptachlor, and trans-nonachlor. It was widely used in the United States as a pesticide from 1948 to 1988 but continued to be produced until 1996, primarily for export. Prior to 1983, the annual production of chlordanne was estimated to be about 3.6 million pounds (1.6 million kg) per year. Production strongly declined after the ban, but it is reported that the United States was still exporting 212.8 tons (200 metric tons) of chlordanne to Mexico as late as 1996. Through the years, chlordanne has had a number of applications including as a fumigating agent as well as use on corn, citrus, vegetables, fruits, and nuts; in home lawns and gardens and on ornamental plants; in turf production; and in ditch banks and on roadsides. It was used to control a variety of insects including termites, ants, parasitic roundworms and other nematodes, cutworms, chiggers, and leafhoppers, among many others, by direct application to both soil and foliage.

### ENVIRONMENTAL RELEASE AND FATE

The most common release of chlordanne into the environment was onto or into the soil. On the surface of the soil, about half evaporated in about two to three days depending upon conditions, but very little evaporated beneath the surface. Once beneath the surface, it adhered strongly to clays and organic particles in the soil and remained fixed for more than 20 years in some cases with very little leaching into the groundwater. It does not easily chemically degrade; nor is it biodegraded. In sandy soils, however, it is more mobile and may leach into the groundwater, where it has been detected in New Jersey and several other areas. The mean degradation rate has been estimated at 4.05–28.33 percent per year with an average removal half-life of 3.3 years for all soils. The highest concentration found in soils was at an EPA Superfund site where it reached 344 parts per million (ppm), and the highest groundwater concentration was 830 parts per billion (ppb). Chlordanne in surface water will evaporate at the surface with a removal half-life of 18–26 days for ponds, 3.6–5.2 days for rivers, and 14.4–20.6 days for lakes. A significant amount of the chlordanne, however, is not removed by evaporation but instead by adhering to organic and clay particles in the water and settling into the sediments. Once in the sediment, it is apparently as persistent as or more persistent than in soils. Chlordanne is greatly bioaccumulated in the aquatic environment, where fish show an average of 3,200 times ambient levels. In the atmosphere, chlordanne is primarily a vapor; it can react with hydroxyl radicals produced by photochemical reactions and be

removed with a half-life of 6.2 hours. It has been estimated, however, that 96 percent of chlordane in the atmosphere has been absorbed onto particulate matter, making it very stable and explaining the ability for long-range transport. It is then removed from the atmosphere by dry fallout or precipitation wash-out. Chlordane has been found as a component in rainwater.

The ecological effects of chlordane are variable. It is considered to be only slightly to moderately toxic to birds, although exposure is significant. It is, however, highly toxic to freshwater fish and invertebrates. Considering the bioaccumulating capacity of chlordane, it can be devastating to aquatic environments. It is also highly toxic to bees and earthworms.

### HEALTH EFFECTS FROM EXPOSURE

Chlordane is thought by some to be among the most dangerous of all environmental hazards, with health risks similar to that of cigarette smoking. It is considered to be moderately to highly toxic with acute exposure. Typically, nausea, vomiting, and abdominal pain are the first signs of chlordane exposure, but in some cases the reactions to it begin with convulsions. Central nervous system effects include initial agitation and irritability followed by depression, loss of coordination, confusion, and exhaustion. Other symptoms can be headache, dizziness, vision problems, muscle weakness and twitching, hemorrhagic gastritis, bronchopneumonia, respiratory failure, and death in high doses. It is highly irritating to the skin and eyes. Chlordane affects the liver; there fore, interactions with medicines, including anticoagulants, steroids, diphenhydramine, and birth control pills, are common.

Long-term chronic exposure of laboratory animals to chlordane primarily damaged the liver and kidneys with some damage to the central nervous system and the endocrine and immune systems. Other effects include decreased fertility by up to 50 percent; nose and eye hemorrhaging; damage to the heart, lungs, and adrenal glands in rats; and death. The EPA classifies chlordane as a group B2 probable human carcinogen. The documented expansive human exposure to chlordane allows epidemiological studies to characterize its effects more accurately than with most pollutants. The noncancerous long-term effects include gastrointestinal and neurological disorders from ingestion and sinusitis, bronchitis, dermatitis, memory loss, personality changes, attention disorders, numbness, disorientation, loss of coordination, seizures, and blood disorders simply from living in a home treated with chlordane for termites. In terms of cancer, it has been associated with increases in leuke-

mia and skin tumors in treated homes and non-Hodgkin's lymphoma among farmers. Mice contracted liver cancer from exposure. Recent studies hint at an even more sinister role for chlordane, associating it with breast cancer, immunological disorders, asthma, and a number of other life-threatening conditions. In support of some of these allegations, chlordane accumulates in human breast milk to 4.4 times the concentration of other compounds.

### REGULATIONS ON HUMAN EXPOSURE

The adverse health effects of chlordane exposure have led to several federal regulations in addition to the ban. The EPA has set a limit of 2 ppb for drinking water and recommends that no more than 60 ppb be present in drinking water that children consume for more than 10 days. Otherwise, for children it should not exceed 0.5 ppb. The EPA further requires that spills of chlordane of one pound (0.45 kg) or more must be reported to the National Response Center. The Occupational Safety and Health Administration (OSHA) limits chlordane in workplace air to 0.5 milligram per cubic meter (permissible exposure limit [PEL]) over an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) has the same recommended exposure limit (REL) as OSHA and a designation of immediately dangerous to life and health (IDLH) at 500 milligrams per cubic meter. On the international level, chlordane is banned in 47 countries and severely restricted in 14 others.

*See also* AIR POLLUTION; ORGANIC POLLUTANTS; PESTICIDES.

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**chlorinated solvents** There are a number of closely related, quickly vaporizing liquid chemicals that are very useful for a variety of industrial processes but wreak havoc when they enter the natural environment. This group, called chlorinated solvents, is produced by many of the major chemical manufacturers. Chlorinated solvents have been used for numerous purposes, including dry-cleaning operations and fluorocarbon manufacture; solvents for fats, oils, waxes, and resins; engine and parts degreasing and cleaning; and paint removal, aerosol propellants, fire extinguishers, organic synthesis, polymer manufacture, foam plastic blowing agents, adhesives solvent, and extraction of caffeine. They were formerly in very widespread use because they are excellent solvents but lack the flammability of typical solvents from hydrocarbon derivatives. The negative health effects of chlorinated solvents that have surfaced in the recent past have resulted in the phasing out of several, to be replaced with less dangerous compounds. Two chlorinated solvents methyl chloroform and carbon tetrachloride, have been implicated in causing damage to the ozone layer and have been phased out for many uses as a result.

### HEALTH EFFECTS FROM EXPOSURE

The health effects of chlorinated solvents depend upon the particular compound in question. In general, most of the solvents will cause damage to the central nervous system, liver, and kidneys, depending upon concentration and duration of exposure. They will also defat skin and cause dermatitis and other skin irritations, as well as irritation of the eyes and mucous membranes. Some chlorinated solvents can be absorbed directly through the skin, whereas others can cause rapid and erratic heartbeat. Still others are known or suspected carcinogens. Several of these solvents have relatively high vapor pressures, so they evaporate quickly. The odors from them are described as sweet smelling and pleasant. The problem is that by the time they can be detected by smell, the concentration in air is higher than the permissible exposure limit (PEL) set by the Occupational Safety and Health Administration (OSHA). Chlorinated solvents are also toxic or harmful to virtually all aquatic organisms.

### ENVIRONMENTAL RELEASE AND FATE

Chlorinated solvents are involved in countless spills and leaks to the point where only petroleum hydro-

carbon (oil) spills are more common. They have caused widespread contamination of groundwater and soil. Chlorinated solvents are commonly present as nonaqueous phase liquids (NAPLs), as dissolved contaminants in groundwater, and as vapors in the vadose zone. The density of these liquids is generally greater than that of water, making them dense non-aqueous phase liquids (DNAPLs), and, as a result, they can sink into and through the groundwater system. This property makes them subject to complex descent paths and dispersal patterns, and, even more important, they are very difficult to clean up. Recovery can be a long process with low product concentration, thus requiring heavy pumping and treatment for minimal removal. In some cases, bioremediation and/or volatilization of product has proven effective to remove them. As a result, natural attenuation may be the best alternative in many of the low-spill/leak volume or low-permeability and/or deep aquifer situations.

The following list contains a short description of the toxicity and health effects of the most common chlorinated solvents. More detailed descriptions can be found under individual compounds.

### CARBON TETRACHLORIDE

Carbon tetrachloride has a contact permissible exposure limit (PEL) of 10 parts per million (ppm) for industry workers, according to OSHA regulations, and can be absorbed through intact skin. Its potential as a carcinogen is debatable. It has been shown to cause cancer in animals and is linked to incidence of liver cancer, but other links are not well established. It can damage the kidneys, liver, and lungs and cause aplastic anemia and rapid, irregular heartbeat, which can be fatal. These negative health effects are exacerbated by alcohol. Carbon tetrachloride also causes headache, dizziness, sleeplessness, and unconsciousness, even with minor exposure.

### Chloroform

Chloroform is best known for its former use as an anesthetic in medical procedures and even in cough medicines. It is now a suspected carcinogen and is proven to cause liver and kidney damage, as well as a rapid and irregular heartbeat. It also produces unconsciousness quickly and headache, dizziness, and sleeplessness. It has a PEL of 50 ppm under OSHA regulations.

### Dichloroethylene (1,2) (DCE)

DCE has been used as an anesthetic for humans, and OSHA regulations permit a PEL of 200 ppm. It is highly flammable and can irritate skin, eyes, and



mucous membranes. It also causes headache, dizziness, and sleeplessness.

#### **Dichloroethane (1,1) (DCA)**

DCA has an OSHA PEL of 100 ppm and is highly flammable. It causes headache, dizziness, sleeplessness, and even unconsciousness at high dosage.

#### **Ethylene Dichloride**

Ethylene dichloride is among the most toxic of the chlorinated solvents and one of the few flammable compounds. It has an OSHA PEL of 1 ppm, but it is debatable as to whether it is carcinogenic. It can damage the liver, kidneys, heart, and digestive system and can irritate or damage the eyes. It also can cause headache, dizziness, sleeplessness, and unconsciousness with even small exposure.

#### **Methyl Chloroform**

Methyl chloroform is one of the least toxic of the chlorinated solvents and is not considered carcinogenic. It can, however, cause rapid and irregular heartbeat and can even be fatal in high doses. Less serious effects include skin, eye, and respiratory tract irritation and dizziness, sleeplessness, and headache. It has an OSHA PEL of 350 ppm.

#### **Trichloropropane (1,2,3)**

Trichloropropane (1,2,3) has an unpleasant odor but is not listed as a carcinogen. It has an OSHA PEL of 10 ppm.

#### **Methylene Chloride**

Methylene chloride has been used in paint removers and as such can cause painful irritation and burns of the skin and eyes. It causes liver and kidney damage, elevated blood carboxyhemoglobin, headache, dizziness, sleeplessness, and unconsciousness, depending upon the degree of exposure. It is also a suspected carcinogen and has an OSHA PEL of 25 ppm.

#### **Perchloroethylene (PCE, PERC, Tetrachloroethylene)**

Perchloroethylene has a PEL of 25 ppm for contact, according to OSHA. It is not considered to be carcinogenic, but it can affect the central nervous system causing such symptoms as headache, dizziness, sleepiness, or unconsciousness, depending upon the degree of exposure. Very high exposure can be fatal. It also can cause irritation of the skin, eyes, and upper respiratory tract.

#### **Propylene Dichloride (1,2-Dichloropropane)**

Propylene dichloride has an OSHA PEL of 75 ppm and is not considered to be a carcinogen. It can dam-

age the liver and kidneys and causes irritation of eyes, skin, and mucous membranes. It also produces headaches, dizziness, sleeplessness, and even unconsciousness at high exposure.

#### **Tetrachloroethane (1,1,2,2)**

Tetrachloroethane (1,1,2,2) has a contact PEL of 1 ppm and has the ability to be absorbed through unbroken skin. It is considered a carcinogen by the National Institute for Occupational Safety and Health (NIOSH) and can cause kidney and liver damage. Even slight exposure can cause headache, dizziness, sleeplessness, and unconsciousness. High exposure can be fatal.

#### **Trichloroethane (1,1,2)**

Trichloroethane (1,1,2) has a contact PEL of 10 ppm and can be absorbed through the skin. It is not considered to be a carcinogen, but it can cause kidney and liver damage. It is a very strong depressant, even more so than chloroform, and can cause headache, dizziness, and sleeplessness.

#### **Trichloroethylene (TCE)**

Trichloroethylene is primarily used as a vapor degreaser and has a PEL of 50 ppm. It is a suspected carcinogen and can damage the kidneys, liver, and lungs. It can also cause rapid and irregular heartbeat that can ultimately be fatal. Less serious effects include skin, eye, and mucous membrane irritation, and dizziness, sleeplessness, and headache. Use of alcohol, caffeine, and drugs of any kind greatly increases the negative effects of trichloroethylene.

See also CARBON TETRACHLORIDE; CHLOROFORM; DCE; METHYLENE CHLORIDE; ORGANIC POLLUTANTS; PCE; TCA; TCE.

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**chlorobenzene** Chlorobenzene was a very important and widespread chemical in the 1950s and 1960s because it was an integral part of the production of many now-banned pesticides such as dichlorodiphenyltrichloroethane (DDT). Now it is primarily an industrial pollutant that workers are exposed to, but the general population rarely has contact with it in everyday use. The main route of exposure is, therefore, through improper handling and accidents or leakage from old landfills. Chlorobenzene also is known as benzene chloride, chlorbenzol, monochlorobenzene, phenyl chloride, IP Carrier T 40, and Tetrosin SP. Chlorobenzene has been found in 97 of the first 1,177 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) in which it was tested. It was rated number 104 of the 275 most dangerous chemicals on the 2007 CERCLA Priority List of Hazardous Substances. It is, therefore, still considered a very dangerous substance.

### PROPERTIES, USE, AND PRODUCTION

Chlorobenzene is primarily a synthesized aromatic organic chlorinated hydrocarbon that is a colorless liquid with an almondlike odor. It is used in the manufacture of rubber, agricultural chemicals, phenol, aniline and dyes, and pigments. Previously, it was used in the manufacture of DDT. It is used as a production solvent for adhesives, paints, polishes, waxes, diisocyanates, pharmaceuticals, dry-cleaning, and rubber. It also has been utilized as a dye carrying agent and fiber swelling agent in textile manufacture, a tar and grease remover, a solvent in surface coatings, and a heat transfer medium. Chlorobenzene production in the United States has declined by more than 60 percent from its peak in 1960. Recent domestic production was 270 million pounds (127 million kg) in 1988 and 231 million pounds (105 million kg) in 1992. This decreasing trend began when DDT and other pesticides were restricted and banned and continued when chlorobenzene was regulated in 1989. This declining use is expected to continue.

### ENVIRONMENTAL RELEASE AND FATE

Chlorobenzene is released mainly from industrial facilities, from improper disposal, or from spills and

leaks during storage and transport. It is primarily a point source pollutant. It is mainly discharged through emissions and evaporation into the atmosphere, where it degenerates through reaction with photochemically generated hydroxyl radicals and photolysis. The removal half-life for this process is estimated at two to nine days. If released into surface water, most of the chlorobenzene will evaporate quickly with an estimated removal half-life of one to 12 hours if the water is rapidly flowing. If it is sequestered into the sediment at the bottom of a lake, biodegradation is the primary removal process, at a removal half-life rate of 75 days. If released into the soil, chlorobenzene will also be mainly removed by evaporation. If the soil is sandy, the remaining chlorobenzene will be mobile and leach quickly into the groundwater system. In groundwater, it degrades extremely slowly by microbial activity. In other soils, the chlorobenzene will adhere to the organic particulate and remain relatively stable. It will degrade slowly by microbial activity as a function of temperature and acclimation of the microbes. There is some evidence of moderate bioaccumulation of chlorobenzene in fish.

According to the last EPA Toxic Chemical Release Inventory, which was conducted from 1987 to 1993, more than 326,000 pounds (148,182 kg) of chlorobenzene was released into the environment by industry over this period. The state with the highest industrial environmental release of chlorobenzene is by far West Virginia, distantly followed by Ohio, New Jersey, Louisiana, and South Carolina. The industry with the highest release rate is alkalis and chlorine production, with far lesser amounts released from plastics, resins, dyes, and industrial organic chemicals.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from exposure to chlorobenzene. Health effects from acute exposure to chlorobenzene include skin, eye, and respiratory irritation; headaches, nausea, sleepiness, numbness, and vomiting in humans; and unconsciousness, muscle tremors, restlessness, and ultimately death in laboratory animals, depending upon the administered dosage. Long-term chronic exposure has been shown to result in muscle tremors, restlessness, increased incidence of pneumonia, and damage to the brain, spleen, liver, bone marrow, and kidneys in laboratory animals, depending upon the amount absorbed and duration of exposure. There were also reproductive effects including decreased fertility in some animals. Chlorobenzene has been shown also to increase the incidence of liver

nodules in rats, but it is not classified as a carcinogen and is considered a group D substance by the EPA, not classifiable as to its potential as a carcinogen.

### REGULATION OF HUMAN EXPOSURE

Public exposure to chlorobenzene is regulated by several federal agencies because of its adverse health effects. The EPA limits chlorobenzene in drinking water to 0.1 part per million (ppm) or less under the Safe Drinking Water Act. They recommend that short-term exposure should not exceed 2 ppm for periods up to 10 days and that levels of chlorobenzene in lakes and rivers should not exceed 0.488 ppm. Any release of chlorobenzene into the environment in amounts of 100 pounds (45.4 kg) or more must be reported to the National Response Center. The Occupational Health and Safety Administration (OSHA) set a limit of 75 ppm of chlorobenzene in workplace air over an eight-hour workday, 40-hour workweek. The National Institute of Occupational Health and Safety (NIOSH) set its immediately dangerous to life and health (IDLH) level at 1,000 ppm for chlorobenzene.

See also DDT; ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**chloroform** Chloroform is the classic anesthetic that was formerly used in medical procedures, kidnappings, and other crimes that required an unconscious victim. It has not been used for some time in medical applications, because it causes too many adverse health effects. Chloroform, also known as trichloromethane and methyltrichloride, and a synthesized organic compound within the class of chemicals called trihalomethanes is one of the chlorinated solvents. It has been sold under various trade names including Formyl trichloride, Freon 20, Methane Trichloride, Methenyl Chloride, Methenyl Trichloride, NCI-C02686, R-20, TCM, and Trichloroform. Chloroform is a colorless liquid that has a sweet odor and taste. It is nonflammable, evaporates quickly, and, in small amounts, dissolves quickly in water. It is an extremely widespread pollutant, identified in 717 of the first 1,430 EPA Superfund sites on the National Priorities List where it was tested. As a result of its widespread distribution and negative health effects, chloroform is ranked the 11th most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

### PRODUCTION AND USE

Chloroform was invented in 1831 and named in 1834. Its first application as an anesthetic was in 1847 in Europe, and it continued to be used throughout the 19th century. It was not utilized as an anesthetic in the United States until the early 20th century, and except for a few specialized procedures, this use was abandoned by the 1940s because of its many adverse effects. The first U.S. manufacturer of chloroform began production of it in 1903, but it was not commercially available until 1922. Over the years, chloroform has been sold primarily as a general solvent for a number of specialty applications including extraction and purification of some pharmaceuticals, including antibiotics, alkaloids, and vitamins, as well as flavors. As a result, it wound up in a variety of medicines and toothpastes until banned in 1976. It was also used as a solvent for lacquer, floor polish, adhesive, resins, grease and fat, gum, wax, and rubber. Chloroform also was commonly utilized as an industrial solvent for photography and dry-cleaning, a chemical intermediate for dyes and pesticides, and a transfer medium for fire extinguishers. Other applications include steel manufacturing, pesticide production, beer brewing,

building and paperboard product manufacturing, and food processing.

Currently, about 98 percent of the chloroform produced in the United States is used in the manufacture of hydrochlorofluorocarbon 22 (HCFC-22), a popular refrigerant (70 percent of usage) and intermediate in the production of fluoropolymers (30 percent). Most of the rest of the uses have been abandoned. To meet the needs of producing HCFC-22, U.S. production of chloroform increased by 20–25 percent in the early 1980s. In 1994, the United States produced 565 million pounds (256.8 million kg) of chloroform and exported 93 million pounds (42.3 million kg) from two manufacturers and 38 suppliers. By 2000, exports had increased to more than 220 million pounds (100 million kg). Chloroform production was greatly decreased over the years because HCFC-22 is a known ozone-depleting compound. It was phased out completely in 2010.

### ENVIRONMENTAL RELEASE AND FATE

Chloroform enters the environment through a number of pathways. Most of it is emitted from a variety of chemical manufacturers as well as paper mills. Leaks and spills from waste sites, storage tanks, and transfer procedures account for part of these industrial emissions and releases. It is reported that approximately 28 million pounds (12.7 million kg) was released into the environment in 1988, but emissions steadily decreased to 5.5 million pounds (2.5 million kg) by 2000. Chloroform in air from industrial processes or evaporated from liquid can settle onto the surface or be washed out in precipitation to some degree. Chloroform is also a by-product of chlorination processes. It is present in wastewater from water treatment plants, but it is also in virtually all chlorinated municipal drinking water. Chlorinated swimming pools can contain much higher levels of chloroform and pose more significant threats through both inhalation exposure and absorption through the skin than some industrial exposures.

Considering all of these sources, it is virtually ubiquitous in the environment, and almost everyone is exposed to chloroform to some degree. The ready evaporation from chloroform-containing liquids, water, and soil means that chloroform moves easily into a gaseous phase, where, once absorbed onto particulate matter or water vapor, it becomes quite stable. Eventually, it breaks down to several compounds, including phosgene and hydrogen chloride, both of which are toxic. In surface water, much chloroform evaporates into the atmosphere, but the remaining liquid is relatively stable. It is relatively

mobile in soil, where only small amounts adhere to clay and organic particles, some breaking down through microbial action and the rest passing into the groundwater system. It is also relatively stable in groundwater.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse effects from exposure to chloroform. The main organs that it targets are the liver, kidneys, and the central nervous system through inhalation, ingestion, and skin (dermal) absorption. Low doses may cause irritability, eye irritation, depression, stomach ailments (nausea, vomiting, and burning during urination), and lethargy. At higher exposure levels, it is a strong anesthetic causing narcosis and possible cardiac arrhythmia, which could be fatal. Long-term chronic exposure typically damages the liver and possibly the kidneys, leading to hepatitis and hepatomegaly. In mice and rats, chronic exposure to high levels produces kidney damage, sperm and testes effects, increased miscarriages, and birth defects. Chloroform is a known carcinogen for animals, causing hepatocellular carcinoma, kidney epithelial tumors, and neoplastic nodules in rats and mice and liver cancer in dogs. Studies suggest a link between long-term chloroform exposure and colon, rectal, and urinary bladder cancer in humans. As the link is still debatable, however, it is listed as a reasonably anticipated human carcinogen.

### REGULATIONS ON HUMAN EXPOSURE

The adverse health effects from exposure to chloroform have led federal agencies to impose strict regulations. The EPA has set a limit of one part per billion (ppb) of chloroform in drinking water and requires that all spills of 10 pounds (4.54 kg) or more must be reported to the National Response Center. The Occupational Safety and Health Administration (OSHA) has set a recommended limit of 50 parts per million (ppm) of chloroform in air for an eight-hour workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set a short-term exposure limit (STEL) of 2 ppm in air for a 60-minute exposure and a designation of immediately dangerous to life and health (IDLH) for exposures of 500 ppm or more. NIOSH estimates that 215,000 workers were exposed to chloroform from 1972 to 1974 but only 95,330 from 1981 to 1983, thanks to more stringent regulations.

*See also* CHLORINATED SOLVENTS; DDT; ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NON-POINT SOURCE POLLUTION; SUPERFUND SITES.



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**chromium** It was hexavalent chromium contamination that affected the small Mojave Desert town of Hinkley, California, for which Erin Brockovich became an environmental advocate. Her story was made famous in the movie version of this well-publicized toxic tort lawsuit. Chromium is an inorganic contaminant and pollutant that has both natural and industrial sources. Chromium is one of the heavy metals common in industrialized areas and was found in an astounding 1,036 of the first 1,591 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (on the National Priorities List) for which it was tested. As a result of this widespread distribution and the health effects it produces, it is ranked the number 18 most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

**PROPERTIES, PRODUCTION, AND USES**

In addition to being a pollutant, chromium is an essential nutrient for good health and an ingredient in most vitamin supplements. The reasons for this apparent discrepancy are both the degree of exposure and the property that chromium exists

in several forms. The three most common forms of chromium are chromium (0), trivalent chromium (III), and hexavalent chromium (VI). Chromium 0 is the metallic version that is used in steel and other alloys. Chromium III is the naturally occurring variety found in the mineral chromite. It also is used in alloys, as a lining for industrial furnaces because of its high melting temperature, and in various compounds including vitamin and mineral supplements. Hexavalent chromium and some trivalent chromium are the mainstay chemicals of many industrial applications including chrome plating, dyes and pigments, leather tanning, wood preservatives, and less commonly in drilling lubricants, rust and corrosion inhibitors, textiles, and toner for copying machines. Hexavalent chromium is by far the greatest environmental hazard and one of the most dangerous.

The United States produces negligible amounts of raw chromium ore, but large quantities are recovered through extensive recycling processes. Despite these recovery and recycling efforts, imports of chromium increased from 485,000 tons (441,000 metric tons) in 2003 to 561,000 tons (510,000 metric tons) in 2007. The primary sources of chromium are South Africa (34 percent), Kazakhstan (18 percent), Zimbabwe (6 percent), and Russia (7 percent).

**ENVIRONMENTAL RELEASE AND FATE**

Chromium is released as both a point source and a nonpoint source pollutant. It is a natural component of most rocks, minerals, and soils and is ubiquitous in the environment as well as a heavy metal industrial pollutant. Chromium compounds in the atmosphere enter mostly from emissions from coal and oil-burning plants, steel mills, and chemical manufacturing plants. They primarily occur in finely disseminated dust particles that typically settle to the surface within 10 days. Tobacco smoke also contains chromium. Precipitation events speed up the settling process. If the chromium compounds settle to soil, they tend to bind strongly to the soil particles and become relatively fixed to them. Other sources of chromium in soil are the disposal of industrial chromium waste and products that contain chromium and removal of chromium from wastewater by filtration. As chromium-bearing precipitates settle into the water, a small amount of chromium may dissolve, but most remains bound to the precipitate and descends onto bottom sediments. Other sources of chromium in water are chromium-tainted wastewater from tanning, textile, and dye and pigment industries. From 1987 to 1993, some 200 million pounds (90.9 million kg) was released into the environment by industry;

most was released by industrial facilities in Texas, North Carolina, Indiana, Ohio, Utah, Arizona, Kentucky, and Pennsylvania.

### HEALTH EFFECTS FROM EXPOSURE

In terms of human health, chromium plays a dual role. Chromium III is essential for the proper uptake and metabolism of sugar, protein, and fat by the body. It is recommended by the American Dietetic Association that adults consume 115 micrograms of chromium III (commonly as chromium picolinate) per day. Chromium deficiency results in weight loss, decreased growth, problems in the nervous system, and conditions resembling diabetes. Too much chromium III, however, can be harmful, and chromium VI should be avoided altogether. Inhalation of high levels of chromium VI from vaporized chromic acid, chromium trioxide, or other compounds typically causes nose irritation, nose bleeding, nasal ulcers, and even holes in the nose and can cause serious asthmatic reactions including shortness of breath, wheezing, and coughing in people who are allergic to it. Chromium III may also cause allergic reactions, and inhalation of concentrated vapors should be avoided. Other effects from inhalation of chromium VI can include gastrointestinal problems and neurological effects. Skin contact with compounds containing concentrated chromium VI has been known to cause chemical burns including redness, swelling, rashes, and skin ulcers. Ingestion of chromium VI causes stomach distress, vomiting, ulcers, convulsions, hemorrhaging, kidney and liver damage, and, in some cases, death. Chromium VI, especially in calcium chromate, chromium trioxide, lead chromate, strontium chromate, and zinc chromate, has been classified as a known human carcinogen, greatly increasing the likelihood of lung cancer through long-term exposure.

Animal studies have suggested other potential human health problems, namely, that a high concentration of chromium VI is extremely toxic and that chromium III is moderately toxic to animals. As did humans, animals exhibited respiratory problems, gastrointestinal problems, liver and kidney problems, various forms of cancer, and death from acute and chronic exposure to chromium VI, and some problems from chromium III. They also showed immune system damage and developmental and reproductive damage. Chromium VI exposure decreases the number of offspring, decreases birth weights, increases birth defects several-thousand-fold, decreases sperm content, and causes the outer cellular layer of curved tubes in the testicles where spermatozoa is produced to degenerate. Developmental effects include skel-

etal and reproductive problems. Acute exposure to chromium III also increases birth defects in mice. Chromium accumulates at much higher levels in newborns and babies than adults. It has been shown to cross the placenta and concentrate in fetal tissue in these studies.

### REGULATIONS ON HUMAN EXPOSURE

As a result of the adverse health effects from exposure to chromium, federal agencies regulate human exposure. The EPA has set the maximal allowable level in drinking water at 0.1 part per million (ppm) (100 micrograms per liter) for both chromium III and chromium VI. For workplace settings, the Occupational Safety and Health Administration (OSHA) has set the maximal occupational exposure limit for chromium in air at 52 micrograms per cubic meter for chromium VI, 500 micrograms per cubic meter for water-soluble chromium III salts, and 1,000 micrograms per cubic meter for chromium 0 and insoluble chromium salts for an eight-hour workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) recommends an exposure limit of 500 micrograms per cubic meter for chromium (0) and (III) for a 10-hour workday, 40-hour workweek and one microgram per cubic meter for all chromium (VI) compounds. The occupations most commonly exposed to chromium are welding, chromate production, chrome plating, chrome pigment production, and leather tanning, although workers in painting, copy machine servicing, printing, cement production, and dye work may also experience risk.

*See also* ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; INORGANIC POLLUTANTS; PACIFIC GAS & ELECTRIC COMPANY; POINT SOURCE AND NON-POINT SOURCE POLLUTION.

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**coal tar creosote** It is surprising that something so widespread as coal tar creosote could be such an environmental threat. Most people see objects containing creosote every day and have contact with them on at least a monthly basis, if not more frequently. Coal tar creosote, however, has been designated as the 23rd worst environmental threat of 275 on the 2007 CERCLA Priority List of Hazardous Substances. Typically associated with coal tar and coal tar pitch, these complex substances cause a variety of environmental problems that directly or indirectly affect human health. Unlike many of the other pollutants, the coal tar products contain numerous pollutants that affect many different ecological systems and organisms. In addition to the toxicity and capacity as a carcinogen, it is this multifront attack and distribution that make coal tar creosote and related substances so dangerous.

### PROPERTIES, USE, AND PRODUCTION

Coal tars are produced by the destructive distillation or carbonization of coal to produce coke or natural gas. Coal tar is distilled to coal tar pitch and creosote. Coal tar creosote is a black- to amber-colored, thick, oily liquid, and coal tar and coal tar pitch are black or dark brown, thick liquids with a smoky odor. Coal tars are actually complex mixtures of up to 10,000 chemical compounds, only 400 of which are recognized. However, fewer than a hundred or so common coal tar compounds (about 85 in one study) constitute up to 98 percent of those present in the environment. The primary components are polycyclic aromatic hydrocarbons (PAHs), which can make up to 90 percent, as well as cresols, phenols, naphthalene, amines, and sulfur-, oxygen-, and nitrogen-heterocyclic compounds, including dibenzofurans. Cresols exist in ortho-, meta-, and para- isomers and are considered a pollutant in themselves in addition

to their contribution to coal tar compounds. Coal tar creosote is the most common wood preservative in the United States and is used on railroad ties (70 percent), utility poles (15–20 percent), bridge and pier decking, log homes, fencing, playground equipment, and concrete marine pilings. Coal tar pitch is primarily used in aluminum smelting but can also be a component of roofing pitch, pipe coating, strengthening of refractory brick, fuel oil, lamp black, antifouling paints, die molds, coking, and steel and iron production. High-temperature coal tar is used to produce tar for road paving, naphthalene, graphite, smokeless solid fuel, benzene, and anthracene paste. Coal tar products are also used in medicine and shampoo to treat skin problems and as pesticides, animal and bird repellent, fungicide, and animal dips.

Domestic production of coal tar began in 1913, when more than 1 billion pounds (454 million kg) was produced through coke production. Coal tar production is closely tied to steel production in the United States because it is a by-product. In 1986, domestic production was 168.6 million gallons (638 million L), and, in 1987, it was 1.8 billion pounds (816 million kg). Domestic coal tar creosote distillate production was 528 million pounds (240 million kg) in 1992. In 1995, one company alone produced 92 million gallons (348 million L) of creosote.

### ENVIRONMENTAL RELEASE AND FATE

Coal tar creosote and coal tar products contain so many compounds with so many properties that release into the environment is generally complex. The main routes of exposure are in sediments, soil, and groundwater, with smaller amounts released into the air. It is mainly a nonpoint source pollutant from all the numerous everyday applications (every utility pole, roof, and road) as well as a point source pollutant from manufacturing plants, improper handling, and spills and leaks from transport and storage. In the past, wood treatment facilities discharged creosote-laden wastewater into lagoons, where it would become sludge. There are many old facilities that may contain significant amounts of highly persistent coal tar creosote and other products.

The many compounds of creosote do different things in the environment. In soil, the phenols, low-molecular-weight PAHs (those that contain three or four atomic rings), benzene, and some heterocycles may evaporate, especially upon application (tarring roofs, driveways, or roads), but once they have set and where they are not used in a liquid form, evaporation becomes a minor process. Movement within the soil is not only a function of wetness, soil chemistry, and structure but also

of molecular weight of the compounds. The high-weight compounds tend to stay fixed, whereas the low-weight compounds tend to be mobile and can leach into the groundwater system. Within the soil, biodegradation dominates reaction removal. The phenols and some heteroaromatic components are readily removed by microbial action while others are highly persistent, requiring years to tens of years for removal. Some of the breakdown products of the creosote are more mobile and toxic than the parent material. If they are released to water, a minor amount of evaporation may occur but within the water, once again, the compounds behave differently. The highly soluble fraction including the phenols, heterocyclics, and low-molecular-weight PAHs primarily dissolve, whereas the high-molecular-weight PAHs attach to particles and settle into the sediment, where they are highly persistent. Creosote can also leach from pilings in water but more so in freshwater than salt water. In addition to that which evaporates, a significant amount of creosote is released from power-plant, industry, and incinerator smokestacks. Wood creosote is released from residential fireplaces. Much of the particulate settles to the ground or is washed out by precipitation. That which persists is primarily the phenols and heterocyclics, which degrade by photochemical reactions.

Coal tar creosote is taken up to a very small degree by plants and terrestrial animals, but significant amounts can accumulate in fish and shellfish. The component that accumulates in these organisms is primarily PAH, and it is that which accumulates into sediments. Concentration factors are highly variable but as high as 73,000 times ambient levels.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from exposure to coal tar creosote and pitch. They may be primarily the result of PAH exposure, but benzene, naphthalene, dibenzofurans, and cresols may also be contributors. Acute exposure produces salivation, vomiting, labored breathing, vertigo, headache, delayed reflexes, hypothermia, cyanosis, and periodic to continuous convulsions followed by coma and death with increasing dosage. There can also be damage to the mouth and pharynx, intestines, pericardium, liver, and kidneys at high doses. Long-term chronic exposure can produce lesions on the skin and eyes, headache, muscle weakness, depression, confusion, vertigo, dizziness, salivation, vomiting, sensitivity to light, corneal damage, and strong allergic reactions. Coal tar creosote has also been suggested to be an endocrine disruptor and to damage



Creosote-treated logs being removed from a kiln at the Summitt Post Company, Shawnee National Forest, Winona, Missouri, ca. 1958 (CORBIS)

the immune system, as well as cause reduced fertility and birth defects.

Coal tars, pitches, and creosote are classified as U.S. Environmental Protection Agency (EPA) group B1 probable human carcinogens, and by the International Agency for Research on Cancer as group 2A probable human carcinogens for creosote and group 1 known human carcinogens for coal tars. As early as 1946, a British study found that patent fuel (a processed hard coal fuel) workers were 500 times as likely to develop scrotal cancer as the general public. Epidemiological studies of other workers exposed to coal tar pitch and creosote—from welders to millwrights to roofers—have found increased incidence of cancers of the skin (primary site), lungs, bladder, kidneys, digestive tract, oral cavity, larynx, and esophagus, as well as leukemia and brain tumors, although many of them are also exposed to other dangerous substances as well. An increase in breast and gastrointestinal cancer is suggested to result from environmental exposure to creosote. Studies on laboratory animals support the epidemiological findings showing an increase in lung and skin cancer and suggesting links to stomach and liver cancer.

The role of creosols in these health hazards is illustrated by the more acute types of symptoms caused by exposure to them. Creosols irritate the skin and eyes, producing rashes, chemical burns, and other skin problems that typically leave scars and other permanent damage. If ingested, they cause burning of the mouth, throat, and stomach, and, in high doses, they can damage the kidneys, cause unconsciousness and coma, and even result in death.



### REGULATIONS ON HUMAN EXPOSURE

The widespread distribution of this dangerous substance has led federal agencies to regulate human exposure. The EPA lists coal tar creosote as a restricted use pesticide (RUP). They also require any release of one pound (0.45 kg) or more to be reported in the National Response Center. The Occupational Safety and Health Administration (OSHA) limits the amount of coal tar pitch volatiles (permissible exposure limit [PEL]) in the workplace to 0.2 milligram per cubic meter of air per eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) similarly established a recommended exposure limit (REL) for the workplace to 0.1 milligram per cubic meter of air per 10-hour-day, 40-hour workweek, and a designation of 80 milligrams per cubic meter. In the 1970s, there were about 145,000 workers involved with the production of coal tar products and 10,000 workers with coke ovens. In the 1981–83 NIOSH National Occupational Hazard Survey, it was found that there were 19,021 workers exposed to coal tar pitch, 7,677 workers exposed to coal tar pitch volatiles, and 7,274 workers exposed to coal tar.

See also BELL LUMBER AND POLE COMPANY; BENZENE; ORGANIC POLLUTANTS; PAH; POINT SOURCE AND NONPOINT POLLUTION; TOBACCO SMOKE.

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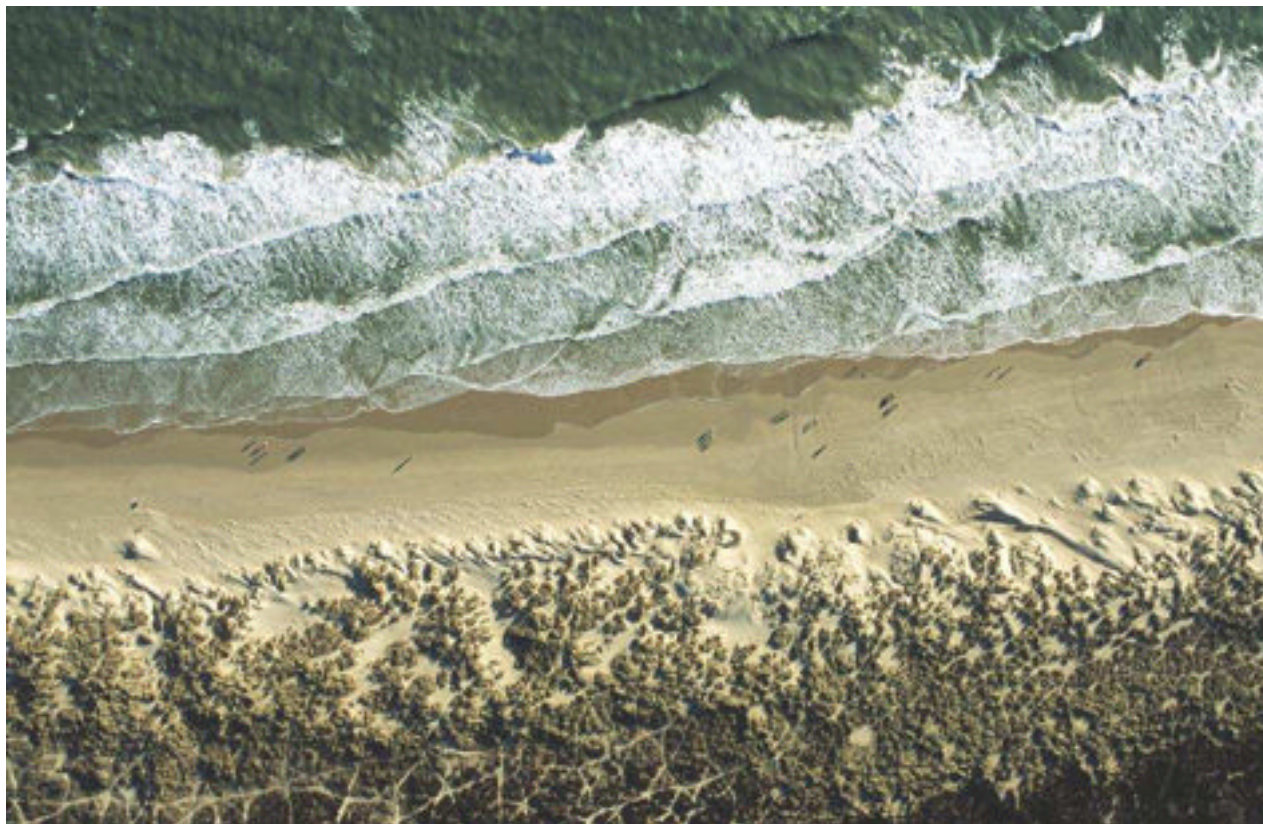
**coastal plain deposits** Where the sea or ocean meets the land, a distinctive group of shallow water marine deposits develops and with time forms an extensive belt along the coast. The belt is a physiographic province called the coastal plain and is generally divided into the Atlantic Coastal Plain along the east coast and the Gulf Coastal Plain to the south. The coastal plain ranges from Cretaceous (140–65 million years old) to modern in age and is mostly composed of unconsolidated sediments. The basal deposits are gravels lying directly on basement rocks but vary in character and composition above them. They form the primary aquifers in these areas, and yet there is extensive industry of many kinds on them. Some of the most dangerous pollution occurs in coastal plain deposits.

### ATLANTIC COASTAL PLAIN

The Atlantic Coastal Plain extends from central New Jersey through Florida. Through most of its length it is composed of clastic sediments, but in Florida it is composed largely of carbonates. The deposits in the north are primarily beach sands, lagoon clays, local gravels, and green sands. The beach and barrier island sands are clean and well-sorted and form huge aquifers. The Kirkwood-Cohansey Aquifer of New Jersey contains trillions of gallons of clean water that is used by millions of people. The sands make up the majority of the stratigraphy of the coastal plain.

Clay deposits are much more common in the older coastal plain to the north and much more extensive in the south. They result primarily from deposition in bays and lagoons, where the water energy is very low. Extensive clay deposits are common when there is a barrier island system along the coast. The larger clay deposits are from periods when barrier islands were common. Clay was mined in the north from several geologic formations (rock types) to make pottery and other ceramics up until the early 20th century and is still mined in Georgia and other southeastern states, where it is referred to as "white gold," because it is so valuable.

There have been several periods of transgressions (rises in sea level) and regressions (drops in sea level) during the history of the Atlantic Coastal Plain. The interaction of salt water with freshwater and terrestrial deposits, and vice versa, can produce distinctive deposits. The New Jersey green sands that are mined for gardening fertilizer are an example of them. They are typically rich in phosphates, radioactive



Waves approaching the beach in Studland Bay, Dorset, England, at an oblique angle (Richard Cooke/Alamy)

elements, and fossils and rest on erosion surfaces. These layers form bands along the Atlantic Coastal Plain that can produce high levels of indoor radon and other environmental problems in houses built on them.

In Florida, the coastal plain deposits are largely limestone, although there are minor interlayered sands. The common transgressions and regressions have produced extensive phosphate deposits across Florida that are open-pit mined for agricultural fertilizer. It is the largest source of phosphates in the United States. The limestones are marked by karst topography. Limestone is so easily dissolved that there are few and only minor streams and rivers in Florida but many circular ponds and lakes filling sinkholes and leading directly into a subterranean cave system.

Pollution in the Atlantic Coastal Plain is largely around urban areas, where industrial wastes slowly infiltrate deeper and deeper into the aquifers. In many cases, the shallower groundwater cannot be used for human consumption. In agricultural areas, the fertilizers and pesticides contaminate the aquifers. In some cases, indirect pollution may result from the infiltration of fertilizer in such places as Long Island, New York, or numerous farming com-

munities in the Gulf Coast. In New Jersey, acidic fertilizer has been found to strip arsenic out of buried clay lenses within the aquifer, thus polluting the water supply. In the Floridan Aquifer of Florida, Georgia, and South Carolina, karst topography can produce a more pronounced environmental hazard. Agricultural runoff and industrial effluence enter the groundwater system directly through sinkholes and are not filtered naturally. The groundwater becomes progressively more polluted.

### GULF COASTAL PLAIN

The Gulf Coastal Plain is far thicker and more extensive than the Atlantic Coastal Plain. It extends from Texas to Florida and as far north as Tennessee along the Mississippi River. It covers the entire state of Louisiana and most of Mississippi and Alabama. It is well more than 30,000 feet (9,144 m) thick in many areas, thinning landward. Unlike the Atlantic coast, the Gulf coast is protected from the power of the Atlantic Ocean, allowing much higher volumes of sediment to accumulate. The sediments are primarily sand and shale, but there is significant salt and some limestone (including chalk) units around Florida and lesser amounts around Texas. The chief





Map of the United States with the unconsolidated sediments of the coastal plain province in green.

difference in composition between the Atlantic and Gulf coast sediments is the amount of mud and shale. The small waves in the Gulf of Mexico allow extensive deposition of mud both in deep water and near shore. The extensive sand deposits are primarily near the rivers and are well preserved in the shale.

The terrestrial sand and limestone units act as aquifers for the area. Limestone aquifers such as the Edwards Aquifer of Texas and the Floridan Aquifer of Florida are major water-bearing units. Sandstone units in Texas and Alabama are also aquifers. The difference between the Atlantic and Gulf Coastal Plains is that mud and shale produced extensive petroleum reserves in the Texas and Louisiana areas both onshore and offshore. The Gulf of Mexico is the major petroleum producing area in North America. The vast amount of petroleum withdrawn from the Gulf Coast sediments is a major economic boon to the area, but it is also very damaging to the environment. The acquisition, transportation, storage, and refining of oil present numerous opportunities for spills. Essentially all petroleum-refining products are pollutants if released into the environment. It is for this reason that the Gulf Coast is among the most polluted areas in the United States. Louisiana's "cancer alley" is a direct result of pollution caused

by the chemical industry that serves the production of petroleum by-products.

See also AQUIFER; BEACHES; CONTINENTAL SHELF; EDWARDS AQUIFER; FLORIDAN AQUIFER; KARST; KIRKWOOD-COHANSEY AQUIFER.

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**cobalt** There are numerous inorganic metals that serve dual roles. Several (chromium, for example) are an essential nutrient and yet, at the same time, an environmental danger. Cobalt is the epitome of the natural duality. It is present in most multivitamin supplements as an essential component of vitamin B<sub>12</sub>. Cobalt sulfate was even added to animal feed and sprayed onto pastures to enhance the health and well-being of cattle, sheep, and goats with outstanding results. It is also, however, a key component in the production of "dirty bombs," which could be used by terrorists to contaminate and disrupt urban centers. One reason for the dual function of some metals is that whereas trace concentrations of many metals are essential to cellular growth and function, large quantities of the same metal can be toxic. The other reason is that cobalt exists in both a stable form,<sup>59</sup>Co, and a less stable, radioactive form,<sup>60</sup>Co. These two forms (isotopes) of cobalt have very different uses. The radioactive form is far more dangerous than the stable form. It is also much more tightly controlled, and there is far less of it in the environment. There are 426 occurrences of stable cobalt found in the first 1,636 U.S. Environmental Protection Agency (EPA)–designated Superfund sites, whereas sampling data have indicated that there are only 13 occurrences of radioactive cobalt at these same sites. As a result of the adverse health effects from exposure, cobalt is ranked number 49 of the top 275 on the 2007 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USE, AND PRODUCTION

There is evidence that cobalt was used in ceramics and jewelry for its blue color as long ago as the third millennium B.C.E. in Egypt. It was first isolated as an element in 1735, whereas the radioactive form was not isolated until 1938. Cobalt is rarely found alone but exists more commonly with ores of other metals such as nickel, copper, silver, and zinc. Cobalt-bearing minerals include cobaltite, erythrite, and skutterudite, and it is used as cobalt metal, cobalt carbonate, cobalt sulfate, cobalt sulfate heptahydrate, cobalt oxide, cobalt hydroxide, and cobalt chloride, among others. The United States produced 405,000 pounds (204,500 kg) of cobalt in 1983 but has produced very little since. Imports of cobalt increased from 9,295 tons (8,450 metric tons) in 2002 to 12,980 tons (11,600 metric tons) in 2006, primarily from Norway (21 percent), Russia (19 percent), Finland (10 percent), and China (9 percent).

Stable cobalt is primarily used in high-tech alloys for aircraft engines and other military-industrial applications, in magnets and magnetic media, as catalysts for petroleum and petrochemicals, as well as in more common applications including electroplating, grinding, and cutting tools; lithographic inks, varnishes, paints, linoleum, batteries, and electrodes; and in pigments for ceramics, enamels, glazes, and porcelain. In addition to vitamins, it is used for some specialized medicines and in replacement hip and knee joints, and it was previously used in beer brewing to stabilize the foam. Radioactive cobalt is used in industrial radiography to image flaws in metals, in food sterilization, in manufacture of plastics, and as focused radiotherapy in the treatment of brain tumors, cancer, and blood vessel irregularities.

### ENVIRONMENTAL RELEASE AND FATE

Stable cobalt is released into the environment from both natural and anthropogenic sources. It occurs in and is released by rock, soil, plants, animals, as well as windblown dust, seawater spray, volcanic eruptions, and forest fires. It is also released by dumping, wastewater, and exhaust gases from mine workings and refined ore residues; processing and smelting facilities for many metals; industries that use cobalt; coal-fired power plants; petroleum refining; incinerators; airplane and vehicular exhaust; and other commercial and industrial processes. Radioactive cobalt is released into the environment from very specific activities such as discharges from nuclear power plants and reactors, nuclear accidents, radioactive waste landfills and ocean dumping, military laboratories, and medical waste. Anthropogenic cobalt in the atmosphere is primarily from combustion and is typically attached to particulate matter that either settles or is washed out of the atmosphere by precipitation (snow or rainfall). The finer the particles, the longer the cobalt remains aloft, and it can remain in the air up to several days. Cobalt in surface water primarily sticks to particles and settles to the substrate, becoming incorporated into the sediments at the bottom of a stream or lake. In some forms, under certain conditions, cobalt may be soluble and remain as ions in water, especially if it is acidic. In soil, cobalt strongly attaches to clay and, in most cases, tends to remain immobile. In some clay-poor, acidic soils, it may be somewhat mobile and leach into the groundwater.

### HEALTH EFFECTS FROM EXPOSURE

There are several negative health effects associated with exposure to stable cobalt. Acute exposure primarily affects the lungs, resulting in wheezing,



asthma, pneumonia, congestion, edema, and lung hemorrhage. Dermal exposure also can cause skin rashes. Long-term chronic exposure also results in asthma, pneumonia, fibrosis, vision problems, immune system and thyroid damage, and congestion of the liver, kidneys, and conjunctiva. Cobalt was formerly used in beer and is implicated in increases in cardiac shock, sinus tachycardia, left ventricle failure, and other damage to the heart. People who consume large quantities of beer may have other reasons for heart problems, and the cobalt association with heart disease is regarded as questionable. Cobalt is considered a reasonably anticipated (more than likely) human carcinogen, as demonstrated by an increase in lung cancer among workers in the cobalt industries. In controlled laboratory experiments, most animals exposed to cobalt showed a distinct increase in lung tumors, and some exhibited an increase in adrenal gland cancer. Rats, guinea pigs, hamsters, and pigs exposed to high levels of cobalt also had damage to lungs, heart, liver, kidneys, and blood. Radioactive cobalt is even more dangerous. Depending upon the exposure, health effects may include nausea, vomiting, diarrhea, bleeding, coma, and even death at high levels. Long-term effects of cobalt exposure may include hair loss, blood damage, temporary sterility, genetic changes in cells, and numerous types of cancers.

### REGULATION OF HUMAN EXPOSURE

Both stable and radioactive cobalt are regulated by federal agencies. The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) of 0.1 milligram of stable cobalt per cubic meter of workplace air over an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set their exposure limit (REL) at 0.05 milligram of stable cobalt per cubic meter of workplace air over an eight-hour-day, 40-hour workweek and a designation of immediately dangerous to life and health (IDLH) of 20 milligrams per cubic meter of workplace air. The EPA regulates exposure to radioactive cobalt to 100 picocuries per liter, or four millirems.

*See also* INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; RADIOACTIVE WASTE; SUPERFUND SITES.

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**continental shelf** The continental shelf is the low-lying edge of a continent that is covered by ocean water. Along those nontectonically active continental margins, where neither subduction (destruction of existing ocean crust) nor extension (formation of new ocean crust) is occurring, the shelf deepens very gradually toward the ocean and so is covered by relatively shallow water throughout its width. The width of the shelf varies by the particular continent and its plate tectonic setting. In tectonically active continental margins with subduction zones (where one plate overrides another), such as the west coast of Central and South America, the shelf is narrow to nonexistent. This is because as the plates crash against one another, the sediments that make up the margin are subducted, or dragged beneath the override plate, and into the upper mantle of the Earth. Instead, steep slopes extend offshore and lie atop highly inclined seafloors that extend into an ocean trench, the deepest places on the planet. Passive margins far from the active edges of tectonic plate collisions and spreading centers, however, such as the east coast of the United States, have wide shelves that extend several hundred miles offshore. The shelves, in these cases, give way to a more gently sloping continental slope, and then the bottom of this leading edge of the continent begins to rise gently in elevation and gradually transitions into the oceanic crust of the seafloor.

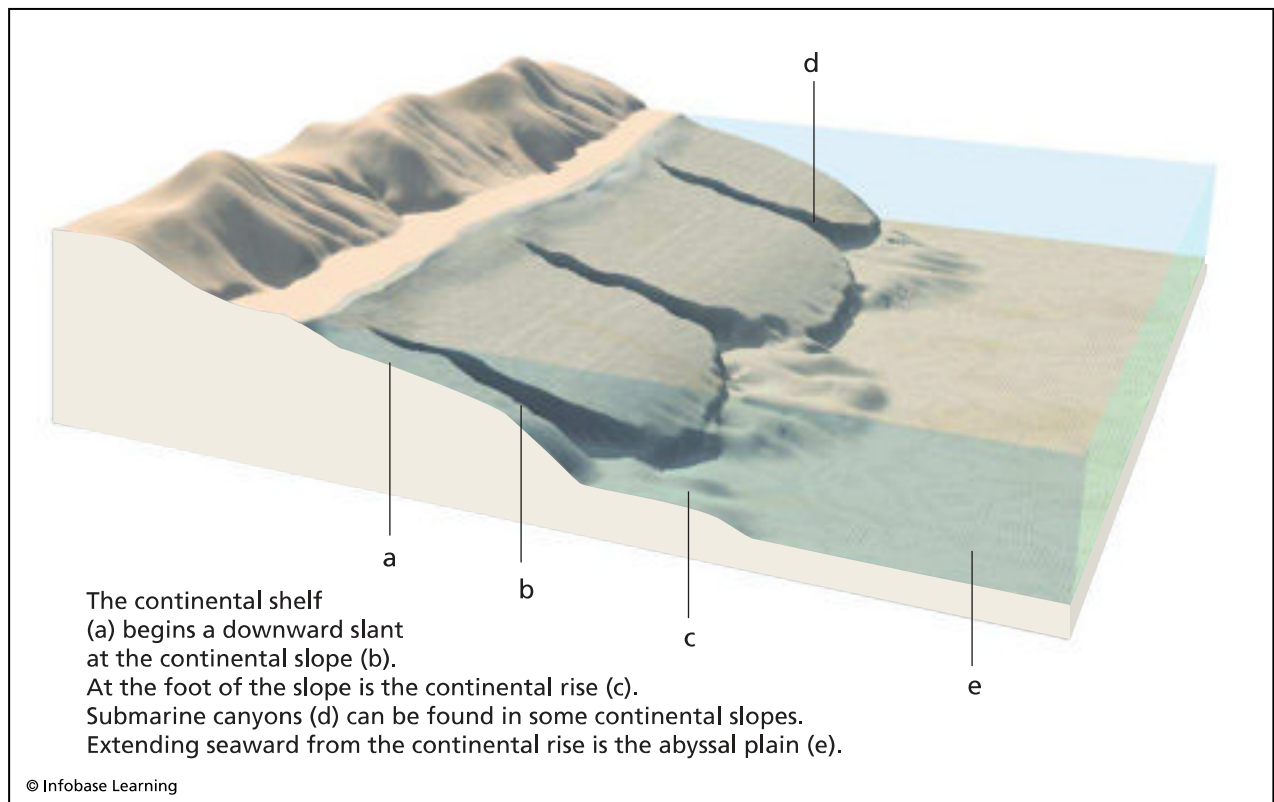
The continental shelves are the breadbaskets of the oceans. The depth of the water is so shallow on the

shelves that the photic zones, that part of the ocean through which sunlight may penetrate, extend across most of the area all the way to the seafloor. Animals and plants that depend on sunlight or on other plants and animal that depend on sunlight must live within the photic zone. In the deep ocean, this means that they can only live in the very top of the water and, therefore, must be floaters and swimmers. On the shelves, however, it means that these plants and animals can live all through the water column and even on the seafloor. This light penetration allows a completely different ecology from that of the deeper ocean. The most commonly developed ocean natural resources (oil and gas, minerals, fish, and other seafood) are from the shelves. In fact, the majority of large, commercially useful species fish (tuna, flounder, etc.) as well as other, lower-value species reside there. The resources of the shelves are critical for human survival. Unfortunately, humans tend to overuse and exploit these shelf-based resources, and the environmental health of these productive areas is in jeopardy. The overfishing and pollution have so damaged the shelves that it is unlikely they can recover without major intervention.

### POLLUTION OF THE SHELVES

Human impacts on the ecology of the shelves have been devastating. In addition to the heavy exploitation of fish and invertebrates that has led to the extinction of many species, humans have used the continental shelves as dumping grounds for waste, munitions, and other unwanted commercial and industrial debris. For years, garbage scows were loaded with refuse, towed offshore, and dumped into the ocean. Millions of tons of garbage and construction debris, among other public refuse, ended up in the ocean. The military has dumped all kinds of ordnance and other arsenal castoffs into the ocean on the shelves. On regular intervals, beaches throughout Europe are closed or restricted because live ammunition is found on them. Both the military and its contractors in Europe, the former Soviet Union, and the United States have dumped numerous barrels of nerve agent in the sea with no records kept of disposal site locations. Additionally, a number of countries have tested conventional explosive devices (bombs and rockets) over the water, causing local phosphorus pollution.

Another example of how human activities contribute to the degradation of the continental shelves



**Block diagram of the continent-to-ocean transition showing the continental shelf, the slope, and the rise: The continental shelf (a) begins a downward slant at the continental slope (b). At the foot of the slope is the continental rise (c). Submarine canyons (d) can be found in some continental slopes. Extending seaward from the continental rise is the abyssal plain.**

is the accidental and sometimes intentional release of refined and unrefined petroleum products. Oil to be delivered to refineries is often transported into ports in tankers. It is rare that tankers leak in open oceans; most accidents and oil spills happen in shallow waters closer to the ports. Although oil can eventually be degraded by bacteria, it is acutely toxic to fish and shore birds. The amount of oil that is spilled into the ocean during these accidents is staggering, and all of it ultimately affects the ecology of the shelves. The average amount spilled per year is 42.7 million gallons (162 million L), but the megaspills can involve 100–300 million gallons (380–1,140 million L) apiece.

In addition to transport accidents, a second major source of spills, not just of oil but of petrochemicals, is from oil extraction–related activities. Most oil is drilled and produced from sediments on the continental shelves, and leaks and spills from drilling and production facilities are also common. In January 1969, America watched more than 200,000 gallons (760,000 L) of oil spill into the Santa Barbara channel before the leaking well could be capped.

Much of the pollution on the shelves is delivered by rivers. The pollution, which depends upon the river and industry that it hosts, can be quite variable. A major problem is agricultural runoff in rivers. Not only can these waters contain pesticides, many of which are toxic to marine invertebrates, but they are also commonly choked with fertilizers. It was previously thought that the ocean was so big that it could absorb anything that humans could produce, but clearly this is not the case. The amount of nitrates and phosphates that the rivers and streams are delivering to the waters of the shelves is producing “dead zones,” caused by hypoxic conditions. The fertilizer introduces large amounts of nitrogen and phosphorus into the water column. These nutrients quickly stimulate indigenous bacterial and algal populations and result in massive algal blooms, which, in turn, promote the growth of bacteria that feed on the algae. The explosive growth of the algae and related bacteria rapidly depletes the oxygen in the water, which is used by these microorganisms in cellular respiration. This lack of dissolved oxygen kills all of the sessile animals and forces the mobile animals to flee. The largest dead zone is in the Gulf of Mexico and is the size of the state of New Jersey, but many other dead zones are appearing and expanding, including a large one off Chesapeake Bay and another off the Oregon coast.

Other sources of pollution to the shelves are air pollution fallout and washout. Industry and transportation in coastal regions along the eastern side of

North America and other continents produce huge amounts of air pollutants that are swept out over the ocean by prevailing winds. Considering the number of cars operating on the East Coast of the United States, the amount of nitrogen fallout into the ocean is significant, as is the particulate and sulfur from the burning of coal and other industrial sources. The entry of nitrogen into near-shore waters adds to the rampant eutrophication (depletion of dissolved oxygen due to the rapid growth of nitrogen-utilizing organisms) of the coastal regions. The same problem is becoming apparent along the east coast of China as well.

*See also* AIR POLLUTION; DEAD ZONE; OIL SPILLS; PLASTIC TRASH IN THE OCEANS.

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**Craney Island Hampton Roads, Virginia 1989–present Soil and Water Pollution** It was a reasonable mistake to make, especially after a three-month sea voyage in a wooden boat on the way to a strange “new world.” To the weary and nervous English settlers who sailed into Chesapeake Bay and toward the mouth of the Elizabeth River in the early 1600s, the tall, elegant birds patrolling the shore of the little island that seemed to be guarding the channel entrance looked like the cranes so commonly seen on the heaths and moors in Scotland and Wales. They named the spit of land Crayne Island, later called Crayne Point, and finally Americanized to Craney Island. The birds turned out to be white and blue herons, not cranes, and they still are regularly seen across this part of Virginia. Despite its poor taxonomical start, Craney Island turned out to be one of the most strategic points of land in the eastern United States.

#### **BACKGROUND**

Recognized early on as a military choke point, the island was quickly fortified by first the English and



later the U.S. Army. During the War of 1812, the British attacked the island but were driven off by American defenders. The victory at the Battle of Craney Island prevented the English from capturing and burning the nearby cities of Norfolk and Portsmouth, Virginia. Craney Island was also an important shipbuilding and dry-dock facility for the Confederacy during the Civil War. In 1861, using the framework of the partly burned and abandoned Union steam frigate *Merrimack*, the ironclad CSS *Virginia* was constructed at a Craney Island shipyard and sent into battle against the federal naval squadron blockading Hampton Roads. The next day, March 9, 1862, the *Virginia* engaged the USS *Monitor* in the famous Battle of the Ironclads.

By the end of World War I, Hampton Roads, the stretch of the Chesapeake Bay near its entrance to the Atlantic Ocean, was emerging as one of the premier commercial and naval ports in the country. In 1918, the U.S. Navy opened its first fuel depot on the island. Today, the four-square-mile (10.4-km<sup>2</sup>) Craney Island Fuel Terminal (CIFT), 17 miles (27.4 km) northwest of downtown Portsmouth, Virginia, is the navy's largest fueling facility in the United States. Made up of more than 1,100

acres (445 has), the facility operates more than 60 aboveground and underground storage tanks with more than 100 miles (161 km) of piping. CIFT's pier-side fuel pump stations and dispensing systems distribute more than 15 million barrels (600 million gallons or 2,271 million L) of petroleum products every year.

### CONTAMINATION OF GROUNDWATER

As a critical component in the nation's defense system, CIFT has operated continuously for almost 100 years. As have many other industrial and military facilities, it has come to recognize and is aggressively addressing a legacy of environmental issues associated with petroleum spills and releases that have occurred during the performance of its mission. These include a leak from an underground storage tank, constructed in 1953, that was cleaned and decommissioned in 1989, when the leak was detected. CIFT is working cooperatively with the Virginia Department of Environmental Quality (VDEQ) to recover the petroleum released from this tank and prevent its spread into potable groundwater or Chesapeake Bay.



USS *Milwaukee* taking on fuel at Craney Island, 1990 (Department of Defense photo, PH3 Martin Norman)



### REMEDIATION ACTIONS

Three recovery wells were installed inside the underground oil plume, and solar-powered skimmer pumps were placed inside each of these wells. A skimmer pump has a hydrophobic (water separating) membrane that rides on the top of the oil-water interface in the well. This membrane allows only petroleum to enter a special collection chamber farther down inside the pump. Once this chamber is full, sensors signal the pump to push it to the surface through a tube, where it is collected in a drum or tank for recycling. The pump is set to run at predetermined intervals to allow the slow-flowing oil to reaccumulate inside the well. Solar panels are used to recharge each system's battery pack, and a telemetry module alerts system operators when the pumps go down, the oil recovery tanks are full, or other types of maintenance are needed.

### Bioremediation

Fifteen acres (6.1 ha) of Craney Island is also being operated as a biological treatment cell (BTC) for the land farming of fuel-contaminated soil. Land farming is an *ex situ* cleanup technology that uses predominantly biological processes to treat contaminated soil. The mechanics of implementing a land farm or land application remedial system are straightforward. The contaminated soil is excavated, sometimes mixed with nutrients (fertilizers) and amendments such as lime or sawdust to adjust pH and organic carbon content, and spread out over a plastic liner. The soil is then periodically tilled (turned over) and irrigated for the next six months to two years. If suitable space is available, land farming can be done on or close to where the contamination occurred. If necessary, however, the impacted soil can be loaded and transported to a more suitable location.

Land farming relies on the activity of a wide variety of microscopic organisms that are present in all biologically active (nonsterilized) soil including bacteria, algae, fungi, protozoa, and actinomycetes. It is the bacteria that are the key to the success of land farming. Bacteria break apart the contamination in order to utilize the carbon present in the contaminant as a food source or substrate. As long as there is enough air and water to support bacterial growth, then the bacteria will attack and destroy the contamination. Land farming is not effective for all contaminants at all sites. It is usually used on soil that contains gasoline or diesel fuel, some types of wood-preserving wastes, and a few pesticides. Compounds that are nitrated or chlorinated are harder to treat via land farming because their carbon is bound up in complex molecules and is more difficult for

the bacteria to utilize. Also, the presence of excessive concentrations of total petroleum hydrocarbons (more than 50,000 parts per million [ppm]) and heavy metals (more than 2,500 ppm) may inhibit bacterial growth and severely slow or prevent significant contaminant degradation. Weather also plays a role. Bacteria work best in warm weather (more than 50°F or 10°C), and in colder climates, such as the northeastern United States, the land farming season is usually only seven to nine months long. In Virginia, the winters are milder, and land-farming operations can be carried out throughout most of the year.

At Craney Island, the land farm facility or biological treatment cell (BTC) is surrounded by a berm to stop surface runoff of oily water. The bottom of the BTC is lined with plastic, which is covered with a layer of sand. Inside this sand layer is a system of pipes designed to collect contaminated water that may infiltrate the treatment cell. A second layer of plastic covers the lower sand layer, and another layer of sand, in turn, covers that. The contaminated soil is spread out over this uppermost sand layer in lifts 12–18 inches (30.5–45.7 cm) thick. It is periodically fertilized, watered, and turned (tilled), to keep it moist and aerated and give the bacteria a chance to work. Once contaminants have dropped to acceptable levels, the soil is excavated and reused at the site.

### Phytoremediation

One-half of an acre (0.2 ha) of the BTC has been designated a phytoremediation study area. Subdivided into six plots, three different plant species (Bermuda grass sod, white clover, and tall fescue) are being evaluated for their ability to biodegrade oily contaminated soil in the rhizosphere (root zone). One plot has been left as an unvegetated control site. The process, called rhizodegradation, is based on the release into the soil of sugars from root exudate, amino acids, fatty acids, sterols, and other compounds and the stimulation or growth of bacterial populations by them. Once activated by these exudates, bacteria start to break apart the organic contaminants in order to use the carbon as substrate. The exudates act to remove nutrients, one of the more common limiting factors to bacterial growth. Given a head start, and partially sustained by root exudates, bacteria can quickly adapt and begin degrading the contaminants in the soil.

Once a month during the growing season, each plot is weeded, mowed, and fertilized. Soil samples are also collected and tested for the nutrients (nitrate, phosphorus, etc.), biomass development (weight of vegetation per square meter), total petroleum hydrocarbons (TPH), and oil in soil pore

water. After two years, TPH concentrations in the vegetated plots were found to be up to 12 percent less than in the unvegetated control plot. Rhizodegradation has been demonstrated as an effective remedial tool on some of the oiliest soils at Craney Island. No by-product wastes were produced that had to be disposed of during this remedial effort, and the cost was not much higher than for maintaining a household lawn. This developing technology offers great promise as a cost-effective and low-impact way to address petroleum-contaminated soil at some sites.

### Dredging

Since the early 1980s, the navy has aggressively pursued several innovative environmental remediation and restoration projects on Craney Island. One that serves both the environment and the local economy is the Craney Island Dredged Material Area, a 2,500-acre (1,012-ha) artificial peninsula in Norfolk Harbor. As sediment is washed into waterways making up Hampton Roads, it needs to be removed or dredged periodically to keep the shipping channels open. Dredged material is pumped into a series of special cells that allow the sand, silt, and clay to settle out and the water to be discharged. The reclaimed land is used as critical habitat for beach nesting birds such as the terns, herons, and gulls, first seen by the British settlers 300 years ago.

See also BIOREMEDIATION; IN SITU GROUNDWATER REMEDIATION; ORGANIC POLLUTANTS; SOIL; UNDERGROUND STORAGE TANK; WATER POLLUTION.

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**Crutzen, Paul Josef (1933– )** *The Netherlands Chemist* Paul Crutzen is one of the most prominent environmental scientists in the world. His

greatest achievement was his pioneering work on the causes of depletion of the ozone layer. This work earned him the Nobel Prize in chemistry in 1995. Crutzen first proposed that oxides of nitrogen might be the cause of ozone depletion in 1970. Arising from heavy use of agricultural fertilizers and internal combustion engines, nitrogen oxides could penetrate the stratosphere, where, through a series of reactions driven by ultraviolet radiation, ozone could be dissociated, or broken into mono- and diatomic oxygen ( $O_3$  to  $O$  and  $O_2$ ). This theory became especially popular in the late 1970s, when supersonic transport (SST) aircraft were being built and were expected to replace conventional jets. SSTs fly higher than normal aircraft and introduce exhaust rich in nitrogen oxides at levels of the atmosphere where they would cause great damage. Fortunately, for economic and market reasons, large numbers of SSTs were never built or placed into service. The potential dangers from chlorofluorocarbons (CFC) would overshadow risks to the ozone layer posed by nitrogen oxide exhaust gases. Consequently, later work by Mario Molina and Sherwood Rowland on CFCs allowed them to share the Nobel Prize with Crutzen.

The second major contribution that Paul Crutzen made to environmental science was to recognize the potential for a nuclear winter in the event of an atomic war. Although Carl Sagan is credited with having proposed the potential for nuclear winter in his famous paper of 1984, Crutzen had had the idea in 1982. He thought that the explosions would ignite most vegetation as well as many structures. The massive amount of smoke generated by the fires of a nuclear war, coupled with all the dust raised by the explosions, would essentially block the Sun for years, sending the Earth into darkness. The deficit of sunlight reaching the surface of the Earth would severely decrease the temperature, thus the term *winter*. The lack of sunlight and cold temperatures would restrict the growth of biomass and set back the progress of life significantly. Whether Carl Sagan independently derived the theory or was influenced by Crutzen cannot be determined, but, in any event, Crutzen deserves the credit for formulating this theory first.

Paul Crutzen has also made some well-publicized arguments regarding global warming. He has stated that the attempts to limit the human production of greenhouse gases have no chance now of even slowing this catastrophe of global warming. Global warming has so changed the climate of the Earth that rather than continue to refer to the current geological epoch as the Holocene, as it is conventionally called, the time after the middle to late 18th century should be called the Anthropocene to reflect

the influence that humans have had on the very processes of the Earth. To address climate change, Crutzen has proposed that we need a radical contingency plan. He suggested that we inject sulfur-rich aerosol particles into the upper atmosphere to block incoming solar radiation and reflect it back into space. This proposal is given serious consideration in most discussions related to developing solutions to global warming and climate change.

Although he is not as popular as many of the scientists in the limelight such as Carl Sagan, Paul Crutzen is one of the most well-known and respected members of the scientific community. He has produced a great number of research articles (220). His influence can be measured by the number of times his work is cited in other articles. Crutzen was arguably the greatest of any environmental scientist in the world for the decade from 1991 to 2001. He had 2,911 citations of 110 of his papers over that decade and was presented an award to commemorate this feat in 2002. This reverence for his work shows how important Paul Crutzen is to the environmental community.

### BIOGRAPHICAL INFORMATION

Paul Josef Crutzen was born on December 3, 1933, in Amsterdam, the son of Anna Gurk and Josef Crutzen. In May 1940, the Nazis conquered the Netherlands, just as Paul was entering elementary school. For the next six years, his schooling was frequently interrupted by World War II. Classes were canceled or delayed or moved to different locations, as buildings they were held in were appropriated for war efforts or destroyed. The cold winter of 1944–45 was called the “winter of famine,” because of severe shortages of food, heating fuel, and water, which resulted in hunger and disease. Several of Paul’s schoolmates died as a result.

Paul Crutzen entered the Hogere Burgerschool (middle school) in 1946 and graduated in 1951, specializing in natural sciences. He then entered the Middelbare Technische School (MTS) to become a civil engineer. Upon graduation in 1954, he accepted a position as civil engineer with the Bridge Construction Bureau of the City of Amsterdam, where he remained until February 1958, when he married his wife, Terttu Soininen. For 21 months between 1956 and 1958, he served a compulsory military tour, as well. After his wedding, Paul and his new wife moved to Sweden, where he obtained a position with the House Construction Bureau of Gälve, the city in which he resided.

It was an advertised position for a computer programmer at Stockholm University that drew Paul to

academia. On July 1, 1959, Paul moved to Stockholm to accept the position in the Meteorology Institute of Stockholm University. In this new job, he helped build the first numerical weather prediction models, as well as tropical cyclone models. As part of his work, he was able to attend classes and complete a master of science degree in 1963. He continued his work toward a Ph.D., but in 1965, through participation on a project with a scientist from the United States, he became interested in ozone distribution. He pursued this direction and completed his Ph.D. in 1968, with a dissertation titled “Determination of Parameters Appearing in the Dry and Wet Photochemical Theories for Ozone in the Stratosphere.” He took a leave from his position as research associate from Stockholm University to accept a European Space Research Organization postdoctoral fellowship at Clarendon Laboratory of the University of Oxford, United Kingdom, from 1969 to 1971. He returned to Stockholm University to continue his research, ultimately earning a doctor of science degree in 1973 with a dissertation titled “On the Photochemistry of Ozone in the Stratosphere and Troposphere and Pollution of the Stratosphere by High Flying Aircraft.” At that point, he became a research professor.

In 1974, Paul Crutzen left Stockholm University to accept a position at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. He first served as a research scientist in the Upper Atmosphere Project in 1974–77 and then as senior scientist and director of the Air Quality Division in 1977–80. During this time, he also worked as a consultant at the Aeronomy Laboratory of the Environmental Research Laboratories of the National Oceanic and Atmospheric Administration (NOAA) in Boulder, Colorado, and from 1976 to 1981 as an adjunct professor at Colorado State University in Fort Collins. In 1980, he returned to Europe to accept the position of director of the Atmospheric Chemistry Division of the Max Planck Institute for Chemistry in Mainz, Germany, and became the executive director of the whole institute from 1983 to 1985. After this, he served as a part-time faculty member at several institutions including the University of Chicago, Illinois, in 1987–91; Scripps Institute of Oceanography, California, from 1992 to 2008, University of Utrecht, the Netherlands, from 1997 to 2000; and the University of Mainz, Germany, where he has been an honorary professor since 1993.

### AWARDS AND HONORS

Paul Crutzen has received numerous awards for his contributions to environmental atmospheric chem-

istry. The most prestigious of these awards is the 1995 Nobel Prize in chemistry, which he shared with Mario Molina and Sherwood Rowland for their individual contributions to the documentation of the depletion of the ozone layer. Other awards include a Special Achievement Award from the Environmental Research Laboratories of the National Oceanographic and Atmospheric Administration in 1977, the Leo Szilard Award for Physics in the Public Interest from the American Physical Society in 1985, the Tyler Prize for the Environment in 1989, the Volvo Environmental Prize in 1991, the German Environmental Prize of the Federal Foundation for the Environment in 1994, the Max Planck Forschungspreis with Mario Molina in 1994, the United Nations Environment Ozone Awards for Outstanding Contributions for the Protection of the Ozone Layer in 1995, and the Accademia dei Lincei in 1997. He was named the Rolex-Discover Scientist of the Year in 1984 and received honorary doctoral degrees from York University in Canada in 1986; Université Catholique de Louvain, Belgium, in 1992; and the University of East Anglia, United Kingdom, in 1994. He was elected to membership in several national science academies including the Royal Swedish Academy of Sciences in 1992, the U.S. National Academy of the Sciences (foreign member) in 1994, and the Russian Academy of Sciences (foreign member) in 1999.

See also GLOBAL WARMING; NO<sub>x</sub>; OZONE; PARTICULATE.

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**Cryptosporidium** *Cryptosporidium* is a resistant protozoan that is the third to fourth most widespread waterborne pathogen in the world. It was first identified in 1982 and since then has been reported in about 100 countries and every continent except Antarctica. The reported infection rates are much higher in developing countries. It was first identified in the United States during an outbreak in Braun Station, Texas, in 1984, and, since then, *Cryptosporidium* has been responsible for millions of infec-

tions throughout North America and Europe. The largest epidemic was in Milwaukee, Wisconsin, in 1993, when some 403,000 cases were documented and traced to inadequate filtration of lake water. It is the relative resistance of *Cryptosporidium* to natural degradation processes and even disinfection practices within its life cycle that make it such a potent agent of infection and public health danger.

#### SOURCES AND DISTRIBUTION

*Cryptosporidium* is a protozoan in the phylum Apicomplexa, which also includes the causative agent of malaria, and develops in the gastrointestinal tract of vertebrates throughout their life cycle. *Cryptosporidium* includes about 10 identified parasite species, which have been identified in more than 150 mammals to date. The species that infects humans is *Cryptosporidium parvum*, but a subspecies of it infects several animals, as well. The life cycle lasts from one to eight days and begins when a sporulated oocyst is ingested by a host. The sporozoites excyst in the small intestines, where the oocyst is produced. This oocyst consists of four sporozoites within a strong, multi-layered shell. The oocyst can then be excreted by the organism, whereby it enters the environment.

The thick chemically resistant wall of the oocyst does not readily decay in the natural environment or with most standard disinfection practices. It can survive for months in cool, dark soils or up to one year in cool, low-turbidity water. *Cryptosporidium parvum* oocysts are more resistant to disinfecting chemicals than most protozoa. Chlorination at drinking water levels and even pool water levels is insufficient to disinfect water of the oocysts. Freezing of water to very low temperatures (one hour at -158°F [-70°C] or 168 hours at -60°F [-15°C]) or heating it above 140°F (60°C) for five to 10 minutes neutralizes the oocysts. Drying the oocysts for one to four days also destroys their infectivity. The best method to remove oocysts from water is with a well-operated filtration system.

*Cryptosporidium* is found in raw sewage but also in surface water, groundwater, and soil. Depending upon the study, *Cryptosporidium* has been found in more than 50 percent of raw sewage samples analyzed. Groundwater varies considerably. In some studies, *Cryptosporidium* occurs in as little as 5.6 percent of the samples, whereas in others it is in up to 87.1 percent of the samples. Streams flowing through pastures and other agriculturally impacted areas have typically elevated levels, as do those streams that have potential impact of raw sewage either by direct dumping or by accidental overflows. Groundwater is typically less impacted than surface water. One study found that five percent of vertical



wells, 20 percent of springs, and 45 percent of horizontal wells were infected. These numbers are area-specific. Deep wells are less impacted than shallow wells, and developed or agricultural areas are more impacted than rural areas. The type of aquifer used is also important. Fractured rock and karst aquifers are much more susceptible to contamination by bacteria and protozoa because of their diminished filtering capacity.

### HEALTH EFFECTS FROM EXPOSURE

After exposure, incubation in humans varies between two and 10 days with the majority between seven and nine days. The main symptom is profuse, nonbloody diarrhea, which usually resolves itself in 48 hours. Other common symptoms include abdominal cramps, vomiting, lethargy, and general malaise. In some cases, *Cryptosporidium* has been linked to renal failure and liver disease, but the cause and effect relationship is not clear. It is also much more serious in patients undergoing chemotherapy for cancer, acquired immunodeficiency syndrome (AIDS) patients, infants and young children, and elderly adults.

See also AQUIFER; WELLS.

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**Cuyahoga River pollution Cleveland, Ohio 1969–present** *Water Pollution* Depending upon where a trip down the Cuyahoga River takes place, it is either wonderfully scenic or very

depressing. This 100-mile- (160.9-km-) long river in northeastern Ohio has its headwaters northeast of the 50-square-mile (129.5-km<sup>2</sup>) Cuyahoga Valley National Park, a quiet and protected area of woodlands, gentle hills, and historic farms, only a short distance from the urban centers of Cleveland and Akron. Not a particularly deep watercourse, the Cuyahoga River has an average depth of only three feet (0.9 m) or so. Fed by the 30+ inches (76.2 cm) of rain that this part of Ohio receives most years, the Cuyahoga's channel has a distinctive U shape. The meandering river's southward course bends sharply to the north near Akron, as it encounters the rocks and sedimentary debris left by the last glacial ice sheet that covered Ohio some 12,000 years ago. The character of the river changes dramatically once it begins its northward trek to Lake Erie, its ultimate discharge point.

The Cuyahoga River was charted in late July 1796, when Moses Cleaveland, a surveyor in the employ of the Connecticut Land Company, arrived at its mouth. Cleaveland walked upstream from where the Cuyahoga enters Lake Erie and found a wide, forested plain. He subdivided the surrounding area into lots, complete with streets, and started a settlement. His colleagues named the new settlement "Cleaveland" in his honor, and four of them stayed behind to serve as the new city's first inhabitants. Moses Cleaveland never returned. Although initial growth was slow (Cleaveland, now called Cleveland, had only 200 residents by the mid-1800s), its strategic location on Lake Erie, good natural harborage, and abundant supply of freshwater from the lake all eventually led to its development as one of the most prominent industrial cities in the midwestern United States. The Cuyahoga River played a major role in that development, both as a navigable waterway and as a convenient method of waste disposal.

### CONTAMINATION OF THE RIVER

By the early 1930s, the Cuyahoga had been straightened, widened, and deepened, to more than 25 feet (7.6 m), by the U.S. Army Corps of Engineers to allow the passage of bigger ships five miles (8.1 km) upriver to almost the center of downtown Cleveland. As a result of the industrialization that followed, in 1936, parts of the Cuyahoga River were so polluted that it could not be used for such common industrial purposes as cooling water or even the shipment of goods by barge. Pollutant levels were so high that the river occasionally caught fire. River fires were not uncommon in the 1890s and early 1900s, and some truly spectacular blazes occurred in other midwestern states, and even on water bodies in New York



Firemen spray water on the tug *Arizona* as a fire, started as an oil slick on the Cuyahoga River, sweeps the docks of the Great Lakes Towing Company in Cleveland, Ohio, November 3, 1952. (© Bettmann/CORBIS)

and Pennsylvania. In 1926, a portion of Baltimore Harbor caught fire, and, in the 1960s, the Buffalo River in western New York burned, and a tugboat burned and sank on the Schuylkill in Pennsylvania when it was caught in an oil slick that had been ignited.

Fires on the Cuyahoga River, however, were much more frequent and intense than on other rivers. Oil and debris in the slow-moving waters of the Cuyahoga reportedly burned in 1868, 1883, and 1887. When sparks from a tugboat landed on oil leaking from a refinery in 1916, they set off a series of massive explosions and a subsequent fire that killed five workers. That event resulted in the passage of a city ordinance prohibiting the release of oil into the river by refineries under threat of a \$10 fine. Surprisingly, not much changed as a result, and a second fire occurred in the same area a decade later, in 1922, and again in 1930. In 1936, the river caught fire once again and burned for almost a week. A survey by the fire department in 1952 found that a two-inch-thick oil slick that had spread across the entire length of the waterway, from the same refinery that had caused fires in 1912 and 1922, was one of the major fire threats in the city.

The same year, a fire started near a tugboat repair and maintenance facility on the Cuyahoga that

burned for more than six hours, with flames shooting five stories high and reportedly causing at least \$500,000 in damage (and possibly up to \$2 million) to a bridge, docks, piers, and barges. The fuel was the unused and waste oil that had been indiscriminately dumped into the river, along with large accumulations of trash and debris that would either wash in or be thrown in by nearby industries and municipalities. The steel mills and oil refineries and terminals that lined the navigable portions of the river did nothing to treat or neutralize their process wastewater discharges, often dumping unrefined or unusable petroleum hydrocarbons, acids, solvents, and other organic chemicals into the river as the most cost-effective and expedient way of dealing with these unwanted by-products. Although industry played a significant role in the destruction of the Cuyahoga as a viable ecosystem, it was not the sole culprit. The city of Cleveland also was one of the major polluters of the Cuyahoga. Cleveland and the surrounding suburbs pumped raw sewage into the river for more than a century without even an attempt at treatment. Oily runoff from roads and nutrient- (fertilizer-) rich overland flow from upstream agricultural areas also contributed significantly to the degraded water quality of the river. Ecologically, the Cuyahoga was a dead river, with one federal study unable to find

even a slight indication of the simplest form of river life, not even leaches or sludge worms that feed on wastes.

The Cleveland City Fire Department became recognized as national experts in fighting river fires. The department was equipped with several firefighting boats, and crews regularly were called out to deal with both large and small conflagrations. Prevention of these river fires became an important part of the fire department's duties, and several crews were specially trained to spot oil slicks and apply chemical dispersants to help break them up.

### PUBLIC CONCERN ABOUT POLLUTION

After the 1952 fire, business and community leaders started to pressure the city of Cleveland to address the pollution issues in the Cuyahoga River. Ten years later, in 1962, press accounts reported that the river was still clogged with debris and heavily polluted, with only the main channel being kept open for barge and river traffic. In 1963, the city contracted with a scavenger service to remove debris from the river, and several of the organizations responsible for the major point source discharges joined together to create the Cuyahoga River Basin Water Quality Committee. The committee implemented a water quality surveillance program and began to plan ways to cut down on discharges to the river.

As the 1960s came to a close, Cleveland, along with many midwestern metropolitan areas, began to lose both population and its industrial base. In addition, concern over the environment was becoming a significant force in American politics. Voters in Cleveland overwhelmingly approved a \$100-million bond issue, in late 1969, with the majority of funding dedicated to the cleanup and revitalization of the Cuyahoga River. These included major upgrades and improvements to municipal sewage treatment plants and a much more aggressive debris removal and antidumping enforcement program. Building on this momentum, a city-financed initiative was established, in early 1969, to examine ways to prevent oil from entering the river and to study ways to remove oil that was already there.

In spite of the concern, just before midday on June 22, 1969, the river caught fire again. It was not a particularly severe blaze: The oil and debris that had ignited were brought quickly under control by the fire department with only minimal damage and disruption to river traffic. This fire, however, would emerge as one of the seminal environmental events in the United States. It also would embarrass the city of Cleveland and give it a reputation as an environmental wasteland for many years to come.

### CUYAHOGA POLLUTION AS AN IMPETUS FOR CHANGE

The 1969 fire occurred just as the country was coming to grips with its need to balance business and manufacturing interests with air and water quality. The national media descended on Cleveland after the fire and, because it had been put out before local film crews could arrive, they resurrected still pictures and newsreel tapes of the much larger and more severe 1952 fire. The Cuyahoga River fire, along with the Santa Barbara oil well blowout and several other high-profile environmental disasters (such as the *Torrey Canyon* and *Argo Merchant* oil spills), would provide the impetus for much-needed federal action on environmental issues. In 1970, the U.S. Environmental Protection Agency was established, the Clean Air Act strengthened, and more than 20 million people around the country celebrated the first Earth Day.

By 1972, thanks in large part to the furor and national attention given to the 1969 Cuyahoga River fire, a revolutionary antipollution law, the Clean Water Act, was enacted. This new law, for the first time, limited the quantities and types of pollutants that could be discharged into the waters of the United States and established a national goal of making every surface water body "fishable and swimmable."

Two popular songs were written about the 1969 Cuyahoga River fire: Randy Newman's 1972 ballad *Burn On* and a 1986 song by R.E.M., titled *Cuyahoga*. The real impact of the fire, however, was to serve as a focal point, or nexus, for the environmental anxiety that many people had begun to feel. Out of this fire arose a new national resolve finally to face the air and water degradation that had been occurring across the United States as a result of more than 100 years of relatively unchecked industrial development.

### CLEANUP EFFORTS

Today, the Cuyahoga River is one of 43 Areas of Concern, or AOCs, included in the Great Lakes Water Quality Agreement. In this agreement, which tries to repair the damage done to the Great Lakes by many years of industrial and municipal misuse, the United States and Canada have decided jointly to prepare Remedial Action Plans (RAPs). These plans will propose the most technologically feasible and cost-effective methods to address beneficial use impacts on Great Lake ecosystems ranging from fish and wildlife consumption to the use of lake water for potable purposes. Of the 43 AOCs, 26 are within the borders of the United States, 12 are in Canada, and five are common to both.



The Cuyahoga River RAP is attempting to address such impacts as eutrophication, the presence of toxic substances (primarily polychlorinated biphenyls [PCBs] and heavy metals) in river water and sediment, bacterial contamination related to sanitary sewer discharges, and habitat modification caused by overdevelopment. Significant progress has been made. Fishing restrictions have been lifted in many sections of the river and habitat improvement projects, such as replacing steel bulkheads with more fish-friendly structures and removing old dams and other obstructions to improve flow and fish passage along the river, have been undertaken. Much work still remains to be done, but fish can be seen in the Cuyahoga downstream from the city of Cleveland, and water quality near where the Cuyahoga empties into the Great Lakes is improving.

See also *ARGO MERCHANT OIL SPILL*; *EUTROPHICATION*; *INORGANIC POLLUTANTS*; *PCBs*; *SANTA BARBARA OIL SPILL*; *TORREY CANYON OIL SPILL*.

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**cyanide** Cyanide has a well-deserved reputation as one of the most potent poisons available. Its dark history as the active ingredient in Zyklon B, the poison gas used by the Nazis in gas chambers during the Holocaust, will never be forgotten. It was also used in the United States for many years for execution in gas chambers and as the potent suicide pill of choice for spies during World War II and the cold war. More recently, the largest mass suicide of all time occurred in Jonestown, Guyana, using a cyanide compound in a drink. With this history and reputation, any amount in the natural environment is of concern.

The devastatingly adverse health effects of exposure to cyanide have earned it the rank of the number 28 most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

#### PROPERTIES, PRODUCTION, AND USE

Cyanide is the name for a chemical group in which carbon is attached to nitrogen with three bonds (CN); it, in turn, is bonded to other elements to form cyanide compounds. Cyanides are both naturally occurring and manufactured as the result of industrial processes. The most common natural source of cyanide is from cyanobacteria, but certain algae and fungi also produce cyanide. It is found in a number of foods including almonds, lima beans, soy, spinach, and bamboo shoots, and in cassava, which is a major source of food in some countries and the source of tapioca in the United States. It can also occur in the pits of certain fruits (apples, apricots, peaches, etc.). The concentration in these sources is generally very low and creates no problems in normal exposure. A person who eats large amounts of fruit pits, however, can ingest a large enough dose to cause adverse health effects and even death. Cigarette smoke and smoke from fires (especially building fires) are more important sources of cyanide exposure. The major industrial sources of cyanide are from blast furnaces and steel production, metal heat treating, electroplating, and polishing. The production of nylon and other synthetic fibers and resins, leather tanning, paper manufacturing, certain types of mining, and, less commonly, herbicides also result in the release of cyanide. About 5 billion pounds (2.3 billion kg) of cyanide is produced in the United States each year through industrial processes. It can also be released from the incineration of municipal and medical waste. When combined with sulfur, cyanide forms the less dangerous thiocyanate group of compounds, which can be found in antibiotics, adhesives, photographic processing and photoengraving, liquid rocket fuel, and matches.

#### ENVIRONMENTAL RELEASE AND FATE

Once in the natural environment, cyanide can be a major problem. In the atmosphere, it mainly occurs as hydrogen cyanide gas with much lesser amounts in fine dust particles. It takes one to three years for one-half of the mass of released cyanide to be broken down and removed, depending upon conditions. Cyanide gas, however, is lighter than air, disperses easily, and generally will not affect the near-surface environment. In surface water, most cyanide forms hydrogen cyanide and evaporates. It does not readily



accumulate and does not bioaccumulate in fish or other aquatic life. In soil, cyanide is fairly mobile and can be removed through several processes. Some can react to form hydrogen cyanide and evaporate into the soil gas and/or escape to the atmosphere. Primarily, it is converted to other, less dangerous chemical compounds by microbial activity. Problems occur when the cyanide is in high concentrations. In this case, it can kill all of the microorganisms and then wash into the groundwater system as the result of its mobility.

### HEALTH EFFECTS FROM EXPOSURE

Cyanide is a deadly toxin. Depending upon the level of exposure, even short single doses of cyanide will result in deep breathing, shortness of breath and weakness leading to headache, vomiting, convulsions, loss of consciousness, coma, and death through cardiac edema and arrest in a matter of minutes whether it is eaten, drunk, or inhaled. It can also be absorbed through the skin, but it is absorbed much more slowly that way, and effects are less intense, although skin lesions are a common result. Even if a victim recovers from a single high dose of cyanide, often moderate to severe brain and heart damage result. Lower doses produce the early effects of a higher dose. Chronic exposure to environmental levels of cyanide can increase its concentrations in the blood. Health effects include restlessness, weakness in the fingers and toes, difficulty in walking, deafness, blurred vision, nerve damage, and decreased function of the thyroid gland. Cyanide has been shown to cause reproductive problems and birth defects in mice and rats, but no definitive connection for humans has been established, even though thyroid disease is a suspected result.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies have imposed regulations on human exposure to cyanide to address the adverse health effects. The U.S. Environmental Protection Agency (EPA) has established a limit of 0.2 part per million (ppm) of cyanide in drinking water and 50 ppm in

stored foods that have been treated with cyanide for pest control. The EPA further requires the reporting and investigation of any spill of potassium silver cyanide that exceeds one pound (0.45 kg) and the spill of hydrogen cyanide, potassium cyanide, sodium cyanide, calcium cyanide, and copper cyanide that exceeds 10 pounds (4.54 kg). The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) for hydrogen cyanide and most cyanide salts at 10 ppm for workplaces over an eight-hour workday, 40-hour workweek. The National Institute for Occupational Safety and Health (NIOSH) set a short-term recommended exposure limit (STEL) of 4.7 ppm of hydrogen cyanide in air averaged more than 15 minutes, not to be exceeded at any time during the workday. They also set the level designated as immediately dangerous to life and health (IDLH) at 50 ppm for hydrogen cyanide and most cyanide salts.

*See also* INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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# D

**DBCP (1,2-dibromo-3-chloropropane)** DBCP was one of the most widely used nematocides and fumigants through the 1960s and 1970s. Serious adverse health effects, however, brought its use into question. One of the most famous of the adverse effects was a marked decrease in male human fertility, ranging to permanent sterility depending upon dosage. Other severe health effects were soon to be discovered and eventually resulted in legislative action to ban its usage in the United States. The first U.S. Environmental Protection Agency (EPA) ban was enacted in 1977 and enforced in 1979; it eliminated all uses except on pineapples in Hawaii. The second ban was enforced in 1985 and eliminated all remaining uses. One would think that the ban would have eliminated all human exposure, but DBCP is so persistent in groundwater that it is still present today, more than 20 years later.

DBCP is also known as BBC 12, Fumagon, Fumazone, Nemabrom, Nemafum, Nemagon, Nemanax, Nemapaz, Nemaset, Nematox, Nemazon, Gro-Tone Nematode, and Durham Nematocide. DBCP was found in only eight of the first 1,177 EPA-designated Superfund sites (National Priorities List) where it was analyzed, and yet it was rated number 44 of the 275 chemicals on the 2007 CERCLA Priority List of Hazardous Substances. It is clear from this high ranking that DBCP is a very dangerous and persistent substance.

## PROPERTIES, USES, AND PRODUCTION

DBCP is a synthetic halogenated aliphatic hydrocarbon and agricultural pesticide that does not occur in nature. It is a dense yellow to amber liquid in technical grade but was also available in emulsifiable

concentrates and granules. It was invented in 1955 and quickly became the nematocide of choice. It was primarily applied directly to soil for more than 40 different crops. Of the 32.4-million-pound (14.7-million-kg) average usage prior to 1977, approximately 12.4 million pounds (5.6 million kg) was used on soybeans, 10.5 million pounds (4.8 million kg) was used on fruit and nut groves, 3.4 million pounds (1.5 million kg) was used on vegetable crops, 3.2 million pounds (1.5 million kg) was used on peanuts, 3.2 million pounds (1.5 million kg) was used on vineyards, and 2.7 million pounds (1.2 million kg) was used on cotton fields. Other applications included golf course and residential grass, ornamental shrubs and plants, and flowers. The highest usage of DBCP was in Arizona, Hawaii, Maryland, North Carolina, South Carolina, and especially the Central Valley of California. DBCP is also still used in the production of flame retardant.

## ENVIRONMENTAL RELEASE AND FATE

As are all pesticides, DBCP was purposefully released to the environment as a nonpoint source toxicant and pollutant. Since its ban as a pesticide in 1979 and 1985, it is only released as a point source pollutant from waste and storage facilities or from the minimal manufacture for chemical applications. If released to the atmosphere, DBCP reacts with photochemically produced hydroxyl radicals and is removed, with an estimated half-life of 12.19 days. In water, DBCP will evaporate relatively quickly but react slowly. The removal half-life by evaporation ranges from 9.5 to 13.5 hours for streams and rivers but 224.2 days for lakes. In soil, DBCP will either evaporate or leach into groundwater under

most conditions. In a sandy soil, it will evaporate from the top 2.5 inches (10 cm) with an estimated half-life of 1.2 days. One study found that it could persist for up to 36 weeks in agricultural soils. Some biodegradation may occur in soil under alkaline conditions (pH of 8) at a rate of 20 percent per week. Otherwise, DBCP binds so weakly to most soils (low organic content) that it will comigrate with water into the groundwater system. Once in groundwater, it is extremely persistent, with reported removal half-lives of 38 years at 77°F (25°C) and 141 years at 59°F (15°C) under neutral pH conditions.

This extreme persistence is reflected by DBCP's being one of only five pesticides to have been consistently found in groundwater surveys throughout the United States. It was detected in 370 community water systems and 38,000 rural domestic wells in the 1990 EPA survey and in 10 percent of the 20,545 groundwater wells tested in the 1992 EPA survey. It is also persistent in some vegetables, remaining in carrots for more than 16 weeks when applied to seedlings.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous serious health effects from both short- and long-term exposure to DBCP. Acute exposure by inhalation primarily affects the central nervous system, beginning with symptoms such as headache, dizziness, nausea, vomiting, and eye, nose, and throat irritation, and progressing to sleepiness, fatigue, muscle weakness and tremors, and double vision. At high dosage, tremors give way to seizures, followed by unconsciousness, coma, and death. Oral ingestion of DBCP results in pulmonary edema and shock within minutes and subsequent death depending upon dosage. Even if the victim survives, resulting brain, kidney, and/or liver damage is likely to be life-threatening. Long-term chronic exposure results in liver, kidney, spleen, eye, and bone marrow damage. It also results in loss of sperm production, the birth of more girls than boys, and permanent sterility in human males with accompanying hormone disruption. In females, there was an increased incidence of miscarriages and birth defects.

The U.S. Department of Health and Human Services has determined that DBCP is reasonably anticipated to be a human carcinogen. Animal studies reveal an increased incidence of nasal cavity, tongue, pharynx, adrenal gland, and lung cancers through inhalation exposure. Other exposure has been shown to cause cancers of the mammary glands, forestomach, stomach, kidneys, and skin. DBCP causes damage to deoxyribonucleic acid (DNA) including mutations and strand breakage in laboratory tests.

### REGULATIONS ON HUMAN EXPOSURE

In addition to the outright bans, federal agencies have imposed restrictions on public and worker exposure to DBCP. The EPA set a maximal level of 0.2 part per billion (ppb) DBCP in drinking water under the Safe Drinking Water Act. They also require the reporting of any spill of one pound (0.45 kg) or more to the National Response Center. The Occupational Safety and Health Administration (OSHA) set maximal levels of 1 ppb in workplace air for an eight-hour-workday, 40-hour workweek.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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**DCB (dichlorobenzene)** Dichlorobenzene has been a very widely used industrial and, less commonly, household chemical that was strongly regulated after it was found to be a potential carcinogen. There are three isomers of dichlorobenzene, or DCB: 1,2-, ortho- or o-DCB; 1,3-DCB; and 1,4-, para-, or p-DCB. Ortho-DCB, 1,3-DCB, and p-DCB have been found in 281, 175, and 330, respectively, of the first 1,662 U.S. Environmental Protection Agency (EPA)–designated Superfund sites on the National

Priorities List. Ortho-DCB is also known as ortho-Dichlorobenzol, Dilantin, Dowtherm E, Chloroben, and Dilantin DB, and p-DCB is also known as Paradichlorobenzene, Paradichlorobenzol, Paramoth, Di-Chloricide, Paradi, Paradow, Persia-Perazol, Evola, and Parazene. As a result of its widespread distribution and adverse health effects, 1,4-DCB is ranked number 159, and 1,2-DCB is ranked number 172, on the 2007 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USES, AND PRODUCTION

Dichlorobenzenes (DCBs) are synthetic chemicals in the category of chlorinated aromatic compounds. Ortho- and 1,3-DCB are colorless to pale yellow liquids at room temperature, whereas p-DCB is a colorless to white solid with a strong, pungent odor. Para-DCB slowly changes from a solid to a vapor (sublimates) when exposed to air. Ortho-DCB and 1,3-DCB have been used to make herbicides, other agricultural chemicals, insecticides for termites and borers, medicines, coolants, degreasers and dyes and used as solvents for waxes, gums, resins, wood preservatives, and paints. Para-DCB has been used primarily as a space deodorant and as a fumigant for moth control (35–55 percent of use) as well as an insecticide on fruit and for control of mold and mildew growth on tobacco seeds, leather, and some fabrics. It also has been applied as an animal repellent and used to make dye pigments and polyethylene sulfide, a plastic for electronics products. DCB was first produced on a commercial basis in the United States in 1915. By 1986, industrial consumption of p-DCB in the United States would top 74 million pounds (33.6 million kg), and, in 1991, production of o-DCB would exceed 43 million pounds (19.5 million kg). In 1997, more than 144 million pounds (65.5 million kg) of total DCB was produced, with exports at 27.1 million pounds (12.3 million kg) by 2000 and growing by 1–2 percent per year.

### ENVIRONMENTAL RELEASE AND FATE

Besides the pesticides that may occur as nonpoint source pollutants, virtually all DCB is released as point source pollution. It is discharged mainly from industrial plants producing organic compounds, alkalis, and dyes. Release is primarily through wastewater for p-DCB and through improper handling and leaks during transport and storage, as well, for o-DCB. If released into the soil, both p-DCB and o-DCB evaporate at the surface but are moderately to tightly bound to the soil particles once they infiltrate. The presence of DCBs in groundwater sup-

plies indicates that they can leach through the soil under certain conditions. Para-DCB was found in 13 percent of surface water samples collected during a national survey. DCBs are not easily broken down by most soil organisms and not broken down at all under anaerobic conditions. DCBs do not dissolve easily in surface water, and most that enters water quickly evaporates into the air (estimated removal half-life of 4.3 hours). Some DCBs bind to particles and settle into the bottom sediment. Sediment cores from Lake Ontario contain DCBs from as early as 1940. Some DCBs that are released to groundwater may be transported through the ground to surface water. Some biodegradation occurs under aerobic conditions in surface water. DCBs released to the air are primarily in the vapor phase and degrade through reactions with photochemically produced hydroxyl radicals, with a removal half-life of 24–31 days. That which binds to particles in the air may be removed by fallout or precipitation washout. Evidence suggests that plants and fish absorb DCBs. Para-DCB has been detected at concentrations of up to 470 parts per billion (ppb) in fish, and the bioconcentration factor tends to be less than 1,000 times ambient concentration, though in some aquatic fish it can be 1,800. Trout from Lake Ontario have detectable levels of o-DCB.

The Toxic Release Inventory of 1987–1993 reported the environmental release of 248,000 pounds (112,727 kg) of o-DCB and 38,500 pounds (17,500 kg) of 1,3-DCB and 34,000 pounds (15,455 kg) of p-DCB, most of which was to water. The state with the greatest releases of o-DCB was by far New Jersey, followed distantly by West Virginia, Oregon, South Carolina, and Texas. The state with the largest releases of p-DCB was West Virginia, followed distantly by Texas, Delaware, Georgia, and Louisiana.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from exposure to both o-DCB and p-DCB. Acute poisoning from inhalation or ingestion of vapor or dusts of o-DCB or p-DCB at very high concentrations is characterized by disturbance of the central nervous system and kidney and/or liver damage, as well as dizziness, headaches, anorexia and nausea, irritation of the eyes, coughing, difficult breathing, and blood dyscrasias. Long-term chronic exposure to DCB has also been shown to produce adverse health effects. The effects are primarily anemia and chronic lymphoid leukemia, skin lesions, and liver damage. There is limited evidence that inhaling p-DCB decreases lung function.



Para-DCB (p-DCB) is classified as reasonably anticipated to be a human carcinogen by the International Association for Research on Cancer (IARC). It has been shown to produce an increased incidence of liver and kidney cancer in laboratory animals. It was also reported that some workers exposed to p-DCB developed an increased incidence of leukemia.

### REGULATIONS ON HUMAN EXPOSURE

As a result of these adverse health effects, federal agencies regulate human exposure to DCB. The EPA has listed o-DCB, 1,3-DCB, and p-DCB as hazardous wastes and restricts their use to hazardous waste regulations. They have set maximal levels of 60 ppb of o-DCB and 75 ppb of p-DCB in drinking water under the Safe Drinking Water Act. They also require the reporting of any spill of 100 pounds (45.5 kg) or more to the National Response Center. The Occupational Safety and Health Administration (OSHA) set maximal levels of 50 ppm for o-DCB and 75 ppm for p-DCB in workplace air for an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set its immediately dangerous to life and health (IDLH) limit to 150 ppm for p-DCB and 200 ppm for o-DCB. The EPA estimated, in 1980, that more than 1 million workers were exposed to p-DCB, and NIOSH estimated exposure of 697,803 workers during their 1971–73 National Occupational Hazard Survey.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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**DCE (dichloroethene)** DCE is an industrial compound that is quite common because it is the primary component of plastic wrap, but it is also a widespread hazardous substance. Dichloroethene, or DCE, occurs in two varieties, 1,1-DCE and 1,2-DCE, the latter forming *cis*- and *trans*- isomers. DCE is also known as dichloroethylene, and for the 1,1 variety it is Asym-dichloro-ethylene, Vinylidene chloride, and Vinylidene dichloride; the 1,2-DCE variety is Acetylene dichloride, *cis*-Z-1,2-DCE, *trans*-E-1,2-DCE, and sym-DCE. The 1,1-DCE variety was found in 492 of the first 1,350 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List), where it was analyzed, and it was rated number 79 of the 275 substances on the 2007 CERCLA Priority List of Hazardous Substances. *Trans*-1,2-DCE was ranked number 173 of 275, and *cis*-1,2-DCE was ranked 270 of 275. *Cis*-1,2-DCE was found in 146 of the first 1,430 Superfund sites and *trans*-1,2-DCE was found in 563. In 336 of the sites, 1,2-DCE was found but no isomer was specified.

### PROPERTIES, USE, AND PRODUCTION

DCE is a synthetic organochloride (chlorinated hydrocarbon) that does not occur in nature. It is a highly volatile and flammable colorless liquid with a mild, sweet chloroformlike odor (1,1-DCE) or a strong, harsh odor (1,2-DCE) depending upon the variety. The 1,1-DCE variety is used in the production of polyvinylidene chloride, adhesives, synthetic fibers (textiles), refrigerants (chlorofluorocarbons), outdoor furniture, food packaging (plastic wrap), and coating resins (including flame retardant), and in chemical synthesis of a number of organic compounds. The 1,2-DCE variety is used as a solvent for dyes, perfumes, lacquers, wax, and resin; in rubber, oil, and fat extraction; as a refrigerant; and in chemical syntheses and pharmaceutical manufacture. Previously, it was used as a gasoline additive and in pesticides, cleaning solutions, paint and varnish, among others. The annual production of 1,1-DCE during the 1980s is estimated at 90,700 tons (82,450 metric tons) per year, 96 percent of which was used to produce vinyl chloride and acrylonitrile. 1,2-DCE

was produced in such small quantities that data are unavailable.

### ENVIRONMENTAL RELEASE AND FATE

1,1-DCE is largely released via spills and leaks from industrial plants and disposal or storage facilities as a point source pollutant. It is so volatile that most of the environmental release is into the atmosphere with lesser amounts into soil and water. When discharged into the atmosphere, 1,1-DCE breaks down quickly through reaction with photochemically produced hydroxyl radicals, with an estimated removal half-life of approximately 16 hours, depending upon conditions. Removal is much more rapid in polluted air (half-life of two hours) but, in any case, it is fully removed within four days. If released into the soil, most evaporates quickly with the remainder entering the soil system. Once in the soil, it is very mobile and leaches into the groundwater system, where it was found in 2.3 percent of samples taken nationwide. In groundwater, 1,1-DCE can be biodegraded to vinyl chloride, a very hazardous substance, but the process is very slow and, in most cases, insignificant. The estimated and observed removal half-life by anaerobic biodegradation ranges from one to three weeks to more than 40 weeks depending upon conditions. If released into water, most 1,1-DCE evaporates from the surface, especially if it is turbulent. Half-life removal rates are 5.9 days for a pond, 1.2 days for a river, and 4.7 days for a lake. The rest dissolves into the water, where it very slowly undergoes biodegradation. The half-life in surface water by chemical breakdown (hydrolysis) is six to nine months at pH between 4.5 and 8.5; other chemical breakdown is even slower. 1,1-DCE is also produced in the natural environment as a by-product of the anaerobic microbial breakdown of trichloroethylene (TCE), so it can be found in groundwater where no direct source exists. It is highly toxic to aquatic organisms.

1,2-DCE also evaporates readily, but it is a bit more persistent than 1,1-DCE. In air, it also reacts with hydroxyl radicals, but the removal half-life is much slower, at five to 12 days. If released into the soil, most of the 1,2-DCE will evaporate, but that which penetrates the soil is highly mobile and leaches into the groundwater system, where the removal half-life is 13–48 weeks depending upon conditions. For this reason, it has been known to migrate long distances from its source. If released into surface water, most of the 1,2-DCE evaporates, and the rest also breaks down slowly. 1,2-DCE is also produced as a natural breakdown prod-

uct of TCE and tetrachloroethylene (PCE) (among the most common groundwater contaminants) and therefore can be found in areas where there is no direct source.

It is reported that more than 11,500 pounds (5,227 kg) of 1,1-DCE was released to water (10,101 pounds [4,591 kg]) and land (1,488 pounds [676 kg]) during the 1987–93 EPA Toxics Release Inventory. The top three states for release were Kentucky, Texas, and Louisiana, primarily from the plastics and chemical industries. While the majority of the releases of 1,2-DCE occur within the Gulf Coast region of the United States, the total quantities emitted are fairly low.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from exposure to both 1,1-DCE and 1,2-DCE (both isomers). Acute exposure to 1,1-DCE results in central nervous system depression that may quickly progress to unconsciousness. Dermal exposure causes irritation, and prolonged exposure can produce first-degree burns. Eye exposure to 1,1-DCE causes irritation and possible conjunctivitis and transient corneal injuries. Long-term chronic exposure to 1,1-DCE causes liver, kidney, and immune system damage and possible birth defects and reproductive problems. The EPA classified 1,1-DCE as group C, possible human carcinogen. Some laboratory animals experienced increased incidence of cancer of the kidneys, lungs, lymph glands, and mammary glands. Experimental studies showed that 1,1-DCE can cause genetic mutations in microorganisms but not in mammalian cells.

Exposure to 1,2-DCE on an acute basis causes eye irritation, nausea, dizziness, fatigue, and sleepiness. At high dosage, it may cause unconsciousness, lung and liver damage, and death of heart failure. Long-term, chronic exposure may also damage the liver, lungs, heart, and circulatory system, as well as cause delayed fetal development. 1,2-DCE is classified as a group D compound by the EPA, not classifiable as to human carcinogenicity. The Department of Health and Human Services, however, determined that it is reasonably expected to cause cancer. This determination was based on a single study that found an increase in lung cancer. Other, similar studies did not connect 1,2-DCE with an increased risk of lung cancer.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies regulate exposure to DCE because of the adverse health effects. The EPA lists 1,1-DCE,

*cis*-1,2-DCE, and *trans*-1,2-DCE as hazardous wastes and restricts their use to hazardous waste regulations. They have set maximal levels of seven parts per billion (ppb) of 1,1-DCE, 70 ppb of *cis*-1,2-DCE, and 100 ppb of *trans*-1,2-DCE in drinking water under the Safe Drinking Water Act. It is recommended not to exceed 3 ppb in surface water bodies. They also require the reporting of any spill of 100 pounds (45.5 kg) or more of 1,1-DCE and 1,000 pounds (454 kg) or more of 1,2-DCE to the National Response Center. The Occupational Safety and Health Administration (OSHA) set maximal levels of one part per million (ppm) for 1,1-DCE and 50 ppm for 1,2-DCE in workplace air for an eight-hour workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set its exposure limit to 1 ppm for 1,2-DCE in workplace air and its immediately dangerous to life and health (IDLH) limit to 3,000 ppm for 1,1-DCE and 1,000 ppm for 1,2-DCE.

See also ORGANIC POLLUTANTS; PCE; POINT SOURCE AND NONPOINT SOURCE POLLUTION; TCE; VOLATILE ORGANIC COMPOUND.

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**DDT (dichlorodiphenyltrichloroethane)** DDT is the most infamous of the pesticides, and the environmental and public health furor resulting from its overuse and misuse significantly fueled the beginnings of the environmental movement that eventually helped to ban it. DDT was invented in 1874, but its effectiveness as an insecticide was not discovered until 1939. Interestingly, Paul Muller, the first person to use DDT as a pesticide, was later awarded the Nobel Prize for his work, even though an African American had made the same discovery years earlier. DDT is one of a group of similar pesticides that were considered to be among the most beneficial substances developed by humans. During the 1940s and 1950s, it was used to control insect-borne typhus and malaria, helping to eradicate malaria-carrying insects from Europe and North America and virtually eliminating lice that carried the typhus bacterium. As a result, mortality rates were reduced 20-fold in a number of locations. Many other insect pests were also reduced, eliminated, or controlled by DDT, and, for decades, it became the insecticide of choice for agricultural applications. With time, many insects would become resistant to DDT, but, by then, environmental concerns related to its bioaccumulation and biomagnifications in the food web would have already heralded its decreasing popularity and ultimate ban.

It was the observations of the negative effects of DDT on wildlife in Nassau County, Long Island, New York, that caught the attention of the naturalist Rachel Carson in the mid-1950s. She and a group of colleagues would battle industry and the government for decades to ban DDT. It is this struggle that led her to write her best-selling book *Silent Spring*, which was a milestone in the establishment of the American environmental movement.

DDT, and its breakdown products, DDE and DDD, have been found in 442 of the first 1,613 U.S. Environmental Protection Agency (EPA)-designated Superfund sites (National Priorities List), which is a very high number for a pesticide. Even though it has been banned since 1972, DDT is still ranked the 12th worst pollutant of the top 275 on the 2007 CERCLA Priority List of Hazardous Substances. The breakdown products DDE and DDD are ranked numbers 21 and 25, respectively. It is because of this widespread distribution and the impressive persistence of DDT that it earned and continues to earn such a high rank.

#### ENVIRONMENTAL TOXICITY

DDT and the related chemicals DDE (dichlorodiphenyldichloroethylene) and DDD (dichlorodiphenyldichloroethane) have been studied for toxicity

more than any other pesticide and perhaps any other environmental hazard, and yet for most health effects, the data are inconclusive. They are certainly health hazards to insects, killing them by exploiting sodium ion channels in the neurons of insects, causing spasms and ultimately death. In animals, short exposures to high concentrations strongly affected the nervous system and the reproductive system, whereas long-term exposure affected the liver. Some studies showed that DDT can cause liver cancer in animals. When mice are exposed to DDT immediately after birth, they commonly have neurobehavioral problems when they are older. DDE in male rats can delay the onset of puberty. It is highly toxic to most aquatic species such as crayfish, shrimp, and many types of fish, in addition to accumulating in the fatty tissue of many others. The problem for animals in the wild is that DDT and its metabolite, or breakdown product, DDE biomagnify (increase in concentration) up the food chain. Probably the best-known effect of the biomagnification was on birds of prey, which sit at the top of the natural food chain. As a result, their reproductive capacity was diminished, and their eggshells were reported to be thinner than normal, ultimately leading to a decline in their numbers during the 1950s and 1960s. Other birds, lower in the food chain, may or may not be affected by exposure to DDT.

### HUMAN HEALTH EFFECTS FROM EXPOSURE

Reports of the toxicity of DDT to humans are conflicting. DDT affects the human nervous system by inducing excitability, tremors, and seizures with high dosage. These effects dissipate quickly, and long-term exposure appears to have no ill effects. It has been shown to affect the liver in some cases. DDE tends to be concentrated in breast milk and reduces lactation. It can also cause premature births. Several studies have suggested that DDT could cause breast cancer, but several others dispute this finding, leaving its potential as a carcinogenic agent inconclusive. As a result of these health effects, the Occupational Safety and Health Administration (OSHA) restricts workplace exposure to 1 milligram of evaporated DDT per cubic meter of air for an eight-hour shift, 40-hour workweek.

### ENVIRONMENTAL RELEASE AND FATE

Previously, DDT was primarily a nonpoint source pollutant that was applied to agricultural and landscaped properties. Currently, however, it enters the environment in the United States only through release from residual concentrations, as it has been

banned since 1972. It is still used in some countries, however. DDD and DDE enter the environment as breakdown products of DDT. All three break down quickly in sunlight with half of the mass not detectable within two days of exposure. They do not dissolve easily in water, so this is by far the most common form of natural attenuation. If DDT enters soil, it strongly adheres to the particles. It is degraded into DDD and DDE by microorganisms at the rate of conversion of half of the mass in two to 15 years, depending upon conditions. Badly tainted soil must be removed and disposed of or washed, depending upon its concentration of DDT.

### POLITICS OF DDT

In the mid- to late 1960s, DDT became more of a political issue than a real health threat. When it was banned in the United States in 1972, there were far worse substances being disposed of in the environment in large quantities. Public pressure in reaction to Rachel Carson's book *Silent Spring* was the whole impetus to ban DDT, even though the book contains then-unsubstantiated claims to its cancer-causing potential. The first administrator of the EPA, William Ruckelshaus, initially fought the ban but was later pressured into enacting it. It was a great political victory for the fledgling environmental movement in the United States. Opponents of the ban claim that it has killed more people than Hitler by allowing malaria and other insect-borne diseases to proliferate. It is true that DDT has saved literally hundreds of millions of human lives. DDT, however, is not as effective in tropical climates, which have been the primary battleground against insect-borne diseases over the past half-century. Additionally, many insects have become resistant to DDT, making it less effective. Even if DDT had not been banned, new pesticides would have had to be developed, and DDT would have had to be phased out anyway. The ban on DDT may be more symbolic than the dire necessity it was portrayed to be.

See also CARSON, RACHEL; ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT POLLUTION; SUPERFUND SITES.

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**dead zone** Eutrophication of freshwater water bodies is well known and widespread. The oceans were traditionally considered to be too large and well circulated to be affected by eutrophication processes. That belief was disproved in the 1960s when a "dead zone" developed in the Black Sea in the USSR. It was called a dead zone because developing hypoxic (oxygen-deficient) conditions suffocated all of the sessile fauna, as well as those with limited mobility, and drove off the mobile fauna leaving an area with few to no fauna. The cause of the problem was excessive agricultural fertilization around the Black Sea. Runoff from these areas after precipitation events flooded all the streams leading into the Black Sea with nutrients. These nutrients, primarily nitrogen (in nitrates) and phosphorus, triggered blooms of phytoplankton, which form the bottom of the food chain. In response to the increased food supply, zooplankton proliferated. When the phytoplankton and zooplankton died, they sank below the photic zone, where, in turn, bacteria proliferated from the increase in food supply and exhausted all of the oxygen in the water. The dead zone, therefore, began in the central part of the water column, spreading both deeper and shallower with time. In these growing dead zones, oxygen concentrations are <0.5 part per million (ppm), in comparison with fully oxygenated seawater, which contains 10 ppm.

### DEAD ZONE DISTRIBUTION

After the initial discovery of dead zones, others were soon detected. The most famous dead zone is in the Gulf of Mexico at the mouth of the Mississippi River. It is about the size of New Jersey, some 7,812 square miles (20,000 km<sup>2</sup>), and expands and shrinks depending upon the season. By 2004, 146 dead zones were reported throughout the world, with the largest measuring some 27,343 square miles (70,000 km<sup>2</sup>). By 2006, the number had grown to 200. The

zones have appeared off Chesapeake Bay; the Oregon coast; the Kattegat Strait between Sweden and Norway; the Baltic Sea, the largest at 39,063 square miles (100,000 km<sup>2</sup>); and the northern Adriatic Sea. New dead zones are developing in the Archipelago Sea, Finland; Mersey Estuary, United Kingdom; Elefsis Bay, Greece; Mondego River, Portugal; coastal waters of South America (Paracas Bay, Peru, and Montevideo Bay, Uruguay); China (Pearl River estuary and Changjiang River); Japan; Southeastern Australia; and New Zealand, among many others.

### CAUSES OF DEAD ZONES

The primary cause of the larger dead zones is the overuse of agricultural fertilizers, but there are many sources. There are even natural sources such as inland flooding, which can cause freshwater to cover a large enough area of salt water to interfere with oxygen exchange. Heavy erosion of soils can add natural nutrients to rivers, and there is evidence of ancient dead zones that predated human colonization in many areas including the Gulf of Mexico. The recent increases in dead zones, however, are all anthropogenic. Increased demand for food leads to increased usage of fertilizers and increases in animal waste, which also cause problems. Automobile exhaust and some smokestack emissions contain significant amounts of nitrogen, which contribute significantly to air pollution fallout. Probably the most significant cause of the rapid increase in new zones in the United States and other areas is the boom in coastal building. Excessive use of fertilizers in lawn care winds up in storm drains and empties into estuaries and directly into oceans. Septic tanks may leak and further contribute to nutrient increases. The heavy development is especially prevalent on the east coast of the United States, which will wind up peppered with dead zones under the current trend. Considering that warm water enhances the phytoplankton blooms, global warming may also be contributing to the development of dead zones.

### ECOLOGY OF DEAD ZONES

The ecology of dead zones is complex. As oxygen levels drop, species respond differently. Once the oxygen levels fall below 5 ppm, fish and many other marine animals have difficulty with respiration. Once levels reach 3 ppm, sharks begin vacating the affected area, whereas most other fish remain until the level is 2 ppm. Marine organisms that cannot escape the area begin dying at 1.5 ppm, and most are dead by the time the typical 0.5-ppm levels are attained. Not all marine organisms, however, are negatively affected. Comb jellyfish, among a few



Map of the world showing the location of dead zones

other species such as stinging sea nettles, can survive in hypoxic conditions and, because of the lack of competition, can actually thrive. These, however, are not desirable species as they consume vast quantities of Zooplankton and eggs and larvae of fish and vertebrates that would otherwise support more ecologically useful species. Atlantic croakers can withstand hypoxia better than most species. They patrol the edges of the dead zones and poach the fleeing, weakened fish as they try to escape. They flourish as a result. Even shrimp trawlers watch for the edges of the dead zones because they tend to be rimmed with fish trying to resist being pushed away from their ancestral spawning/feeding grounds. They have record catches from these areas.

There is very little good news with regard to dead zones. Two bright spots are in the largest dead zones in the Black Sea and the Baltic Sea. The collapse of the Soviet Union, in 1989, ended the centrally planned economies in Eastern and Central Europe. The extensive agricultural activities were strongly curtailed, and fertilizers became too costly to use in excess. Between 1991 and 2001, the Black Sea dead zone, which had been the biggest in the world, largely disappeared. The Baltic Sea dead zone is still the largest in the world and a permanent fixture. Oxygen levels have slowly risen in the zone, and some species are even returning after many years

of absence. The collapse of the Soviet Union is part of the reason; another is that countries along the Rhine River have initiated policies that have limited nitrogen input. As a result, the North Sea dead zone shrank by 37 percent between 1985 and 2000.

See also EUTROPHICATION.

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## Gulf of Mexico Dead Zone

There is an area just south of the mouth of the Mississippi River in the Gulf of Mexico that annually develops conditions of hypoxia. The zone appears in February and grows continuously into the summer, when it peaks in size before dissipating in the fall as large storms sweep in. The average size of the zone is 5,000 square miles (13,000 km<sup>2</sup>), but, in 1999, it grew to 7,700 square miles (20,000 km<sup>2</sup>), or roughly the size of New Jersey, and it was even larger in 2001. This area has been called a dead zone because the oxygen levels drop so low (<2 mg/L) that fixed or slow-moving marine life such as crabs, clams, snails, worms, and echinoids slowly suffocate. The quick-swimming animals abandon the area at the first sign of trouble. Thus there are very few, if any, living animals in the zone of hypoxia.

The Gulf of Mexico dead zone is caused by the influx of huge amounts of nitrogen as nitrate primarily from the Mississippi River. The river delivers 140

cubic miles (580 km<sup>3</sup>) of freshwater drained from 31 states and more than 41 percent of the continental United States. Half of the nation's farmlands drain into this freshwater either through tributaries or directly into the river. The amount of fertilizer used on these farms has increased dramatically since the 1950s. The amount of nitrate from fertilizer delivered into the Gulf of Mexico from the river tripled between 1960 and 1997, and the amount of phosphates, another fertilizer, doubled during the same period. More than 1.75 million tons (1.6 million metric tons) of nitrate per year was being introduced through the river by the late 1990s, 30 percent of which is estimated to originate from agricultural fertilizers, 30 percent from natural soil decomposition, and 40 percent from several sources including animal waste, sewage treatment plants, and air pollution fallout from industrial and transportation sources.

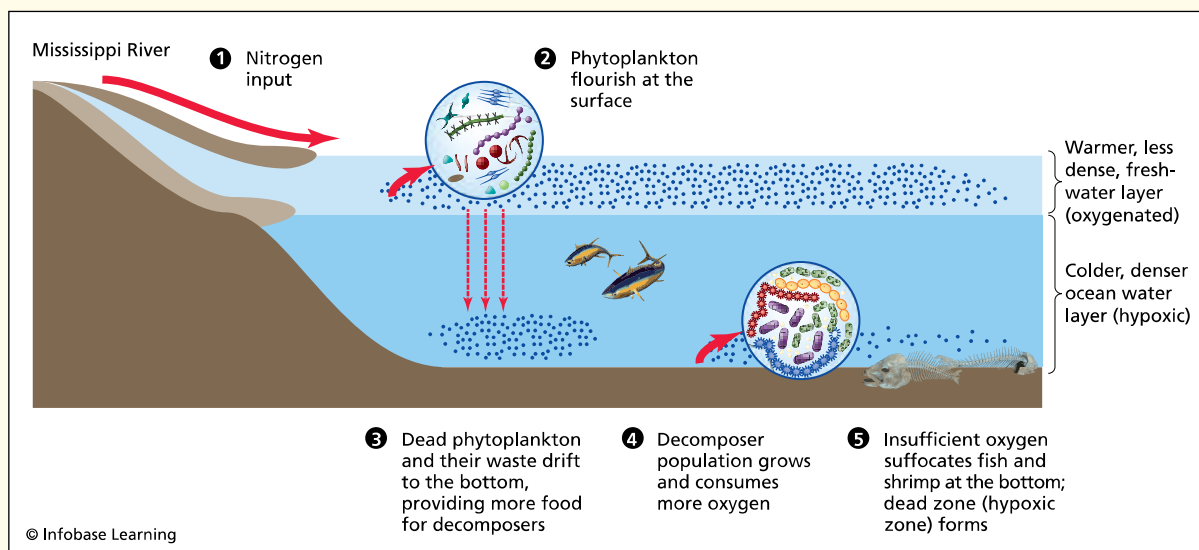
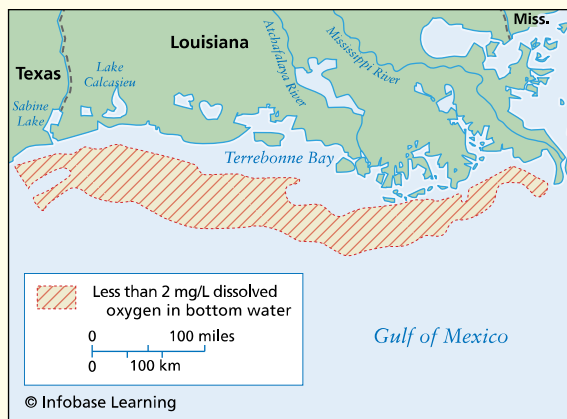


Diagram showing the steps in the eutrophication of the Gulf of Mexico at the mouth of the Mississippi River and the subsequent development of a "dead zone" as the result of excess input of fertilizer

**Deepwater Horizon oil spill U.S. Gulf of Mexico (April 20, 2010, to September 19, 2010) Water Pollution** Two days before Earth Day, on April 20, 2010, a semisubmersible drilling rig, the *Deepwater Horizon*, experienced an uncontrolled, catastrophic release of pressure known as a blowout during drilling operations about 40 miles (64 km) south of the coast of Louisiana in the Gulf of Mexico. The explosion and massive fire that followed killed 11 people, injured 17, and caused the worst off-

shore oil spill in U.S. history. The drill rig was under lease to BP (British Petroleum) and was owned and operated by Transocean, Ltd. one of the largest oil-drilling companies in the world. Over the next three months, up to 2.5 million gallons (9.5 million L) of oil were released daily into the Gulf of Mexico. This blowout became the most severe environmental crisis to occur in a U.S. territory. The *Deepwater Horizon* disaster, however, was not the first such disaster in the petroleum-rich Gulf of Mexico.



**Map of the hypoxic dead zone in the Gulf of Mexico at the mouth of the Mississippi River shown by the shaded area**

When the nitrates (and phosphates) enter the Gulf of Mexico, they act as nutrients for algae, whose populations grow rapidly in a “bloom.” A complex sequence of events then ensues in which organisms that feed on the algae also grow rapidly and produce huge amounts of waste. All of the waste triggers the rapid growth of bacteria that feed on the waste from both the algae and consuming organisms and, in the process, use up all of the dissolved oxygen in the water. The hypoxic zone grows from deeper levels to near the surface as it develops. The water undergoes eutrophication, which results in the death or driving off of all life in the affected zone. The zone grows larger as more nutrients are added to the water as long as there are no storms or other events that can disrupt the system.

The dead zone was first recognized in the Gulf of Mexico in the 1970s, but the location could not be accurately mapped until the 1990s. The problem is that it moves around from year to year and changes sizes and shapes. It has now been mapped fairly accurately for the past 21 years. It is controlled by a number of factors including the amount of fertilizer used in the midwestern farmlands, the extent of precipitation and

runoff in the farmland relative to precipitation in other areas of the Mississippi drainage basin, water temperature in the gulf, and the number of hurricanes and other storms in the gulf. The ideal situation is heavy fertilizer usage and precipitation in the farming areas along the Mississippi and drought throughout the rest of the basin and a calm, warm Gulf of Mexico.

The dead zone is devastating to the fishing industry in the gulf and even results in unexpected consequences such as an increase in shark attacks along the coast because of the lack of food for them. For that reason, an agreement was reached and law passed on October 11, 2000, to allocate \$1 billion per year until 2015 to reduce the amount of nitrogen in the Mississippi River by 30 percent. It is not an easy task because population growth adds nitrogen directly to runoff by increasing residential areas and automobiles and indirectly by placing higher demand on agricultural areas for more food.

*See also* CONTINENTAL SHELF; EUTROPHICATION.

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—by Alexander E. Gates

### GULF OF MEXICO PETROLEUM

In Late Triassic period, some 230 million years ago, the breakup of the global supercontinent Pangaea was well under way. The North American plate had started to move (rift) away from the African and South American plates. The new ocean crust created in the gaps between these plates formed a low-lying geologic basin, or depression, by the Middle Jurassic (170 million years ago) that today makes up the Gulf of Mexico. The continental landmasses of North America,

Mexico, the island of Cuba, and parts of the Caribbean surround and define the Gulf of Mexico basin.

After its formation, the Gulf of Mexico entered a long period of geologic quiescence. During this time and continuing today, the freshwater of more than 150 major rivers that drained almost 1.5 million square miles (3.9 million km<sup>2</sup>) of North America empty every year into the 600,000 square miles (1.6 million km<sup>2</sup>) of the Gulf of Mexico basin. These 280 trillion gallons (1,060 trillion L) of freshwater



carry clay, silt, sand, and gravel, as well as dissolved ions of potassium, calcium, and sodium. The gentle waves and small tidal fluctuations allowed most of this sediment to deposit rather than be washed away, as it does in larger ocean basins. Eventually, a ring of sediments deposited around most of the outer edge of the basin, forming a wide, gentle mantle of unconsolidated silt, sand, and gravel deposits on the continental slope. Farther seaward, a blanket of sediment more than nine miles (14.5 km) thick created and then buried subbasins, channels, and valleys. These features formed as sea level fluctuated in response to plate tectonic movements, glaciations, and local climatic changes.

The carbon-rich organic matter from the remains of plants and animals were also carried with the sediments by the rivers. As the continual in-pouring of sediments compressed the organic material, it was heated, pressurized, and eventually converted into oil and gas through a complex series of chemical reactions and accumulated in geologic features known as oil and gas “traps” deep beneath the seafloor.



**The *Deepwater Horizon* on fire after a catastrophic failure of its blow-out preventor and related safety systems (U.S. Coast Guard photo/Released)**

## GULF OF MEXICO RESOURCES

Petroleum geologists estimate that there are 4,300 billion barrels (684 trillion L) of recoverable petroleum and 170,000 billion cubic yards (130,000 billion m<sup>3</sup>) of usable natural gas beneath the seafloor of the Gulf of Mexico. Current offshore exploration and production operations employ 60,000 workers and produce about 25 percent of U.S. natural gas and almost 13 percent of domestic oil. Mexico reports oil production from the gulf in the range of 2.7 million barrels (430 million L) and more than 52 million cubic yards (40 million m<sup>3</sup>) of natural gas. Oil production and exploration companies have drilled about 4,000 oil and gas extraction wells in the Gulf of Mexico.

Behind oil and gas, tourism (recreational bathing and sports fishing) is the second-largest industry in the Gulf of Mexico, with an annual value of more than \$100 million. Every year, tens of thousands of people visit the sandy beaches to enjoy the warm, gentle waters of the Gulf Coast. Almost 20 percent of the nation's seafood comes from the Gulf of Mexico, where commercial fishermen harvest 2 billion pounds (0.9 billion kg) of fish and shellfish annually. This \$1-billion-a-year industry represents a significant portion of the economies of the five Gulf Coast states: Texas, Louisiana, Alabama, Florida, and Mississippi. The 3,500 miles (5,633 km) of inland bays, shorelines, estuaries, and wetlands also host thriving ecosystems for migratory birds as well as for thousands of indigenous plants and marine mammals and upland animals.

## DRILLING THE MACONDO PROSPECT

In early spring 2010, oceangoing tugs moved a relatively new offshore drilling rig, the *Deepwater Horizon*, into position. The *Deepwater Horizon* was to drill an exploratory oil well into a promising area within a portion of the Mississippi Canyon, a submerged, steep-side valley on the seafloor of the Gulf coast's continental slope. In 2008, BP, formerly British Petroleum and one of the largest energy companies in the world, purchased the right to drill for oil in the area from the U.S. Minerals Management Service, or MMS. BP code-named the Macondo prospect from a fictional town described in Gabriel García Márquez's Nobel Prize-winning novel *One Hundred Years of Solitude*. The MMS was the government agency that, until recently, was responsible for promotion, oversight, and regulation of offshore mineral resources, including oil and gas exploration and development. BP estimated that the Macondo prospect or reservoir might hold 50 million barrels (8 billion L) of recoverable oil, in addition to

significant amounts of natural gas. Geologists have calculated that the reservoir is some 13,000 feet (4 km) below the sea floor and at one mile (1.6 km) water depth.

Once the *Deepwater Horizon* was in position, operators partially flooded the pontoons upon which the drilling platform floated. This brought the rig to an appropriate operational height and provided the ballast needed to maintain a stable working platform. A computer-controlled set of propellers and thrusters would keep the rig centered over its borehole as powerful drill bits cut through seafloor sediment and rock in search of oil and natural gas. The rig positioning system, called dynamic propulsion, turned thrusters on and off based on input from special sensors that could read wind speed, direction of current, and other factors affecting the position of the drilling platform. Constructed in 2001, the *Deepwater Horizon* was designed to operate in up to 8,000 feet (2.4 km) of water and drill up to 30,000 feet (9.1 km) into the sea floor.

The Gulf of Mexico has an average water depth of approximately 5,300 feet (1,615 m). Oceanographers postulate that in its deepest portions, called abyssal areas, water depths are 12,500 to 14,100 feet (3,800 to 4,300 m). Operating a drilling platform almost a mile above the seafloor is complicated. The thick-walled steel pipes and powerful bits, clamps, and tools that are strong on the surface can behave as if soft and plastic when lowered deep below the surface where water pressures are in excess of 300,000 pounds per square foot (1.46 million kg/m<sup>2</sup>).

Although the specific procedures used on the *Deepwater Horizon* are not yet widely available, it is likely that Transocean, Ltd., installed the well in a manner similar to that described below.

When a deepwater (depths greater than 1,000 feet [305 m]) offshore well is drilled, steel pipe or tubing, called casing, is lowered to the seafloor and pushed or hammered several hundred feet into the loose sediment. This process, called “spudding in,” provides the main structural support for the installation of the drill pipe. The casing is usually 36 inches (0.9 m) in diameter but can be as wide as 72 inches (1.8 m) depending on the depth of the well and sediments through which it is drilled. In the Gulf of Mexico, overlying sediment is so unconsolidated that casing often can be “washed” into place by using powerful jets attached to the end of the steel pipes. Once platform crews (sometimes referred to as roughnecks) install the casing, the next step is to assemble the drill string of 30- to 45-foot- (9.1- to 13.7-m) long sections of six-inch (15.2-cm) diameter steel pipe connected together to the desired length and attached to a diamond-tipped drill bit at the

end. The operator lowers the drill string from the platform and threads it like a needle into the top of the wellhead a mile below the water’s surface. Platform crews sometimes accomplish this with the aid of remotely operated submersible vessels.

The driller rotates the string by engaging a powerful engine through hydraulic gears attached to a drive mechanism (called a turntable) on the platform and adds sections of drill pipe as needed to advance the well. The bit at the end of the string cuts through the sediment and begins to extend the borehole below the seafloor. During drilling, platform personnel pump a specially formulated mixture of water, barium, and clay, called drilling fluid or mud, through the center of the drill pipes into the borehole. Drilling mud keeps the drill bit cool and flushes particles of displaced sediment, called cuttings, to the top of the wellhead.

The most critical reason platform operators use mud is to manage the pressures encountered during drilling. Forcing a narrow-diameter pipe deep into the ground is similar to coring through the cork of a champagne bottle. The oil and gas are under tremendous pressure, and if encountered unexpectedly they quickly expand and rise up through the borehole, driving the drill string, casing, and everything else in their path toward the surface. Drillers call this a “kick” and balance the pressures by forcing more and heavier drilling mud into the borehole.

As the borehole is deepened, usually between 1,000 feet to 2,000 feet (305 m to 610 m) into the seafloor, the drill string is withdrawn and the platform operators thread another length of casing, 22 inches (55.9 cm) in diameter, through the 36-inch- (0.9-m) diameter casing and join the two together using special fittings. One of the most critical parts of the operation is the grouting in place of the “22” using high-pressure, quick-setting concrete. A mistake in grouting renders the structural stability of the well suspect and is very expensive and difficult to correct.

Once “22” grouting is completed, operators attach the blowout preventor (BOP) and marine riser to the top of the wellhead casing on the ocean floor. The BOP can be up to five stories tall and weigh upward of 400 tons (363 metric tons). It is a sophisticated set of control or cutoff valves, with numerous backup systems that shut if a “kick” occurs, stopping the high-pressure escape of oil and gas from the well. This prevents the uncontrolled release of fluids (oil) or natural gas and allows the driller to counterbalance the expected or unexpected rise in pressure by pumping heavier drilling mud into the borehole. If a kick occurs, the force exerted on the well casing is severe and therefore requires that the

grout secure it firmly in place. A blowout occurs if the BOP fails and oil and gas gush from the well in an uncontrolled manner. Blowouts, which can result in the accumulation of highly flammable and explosive concentrations of oil and natural gas on and underneath the drilling platform, are extremely dangerous and have been responsible for the deaths of many oilfield and offshore platform workers (see *PIPER ALPHA OIL SPILL*). Installing and testing BOPs are some of the most important components of a drilling platform's safety program.

Connecting the top of the subsea wellhead and the BOP to the drilling platform is a sequence of hollow steel pipes called the marine riser. It is through this that platform operators lower the drill bit, drill string, and mud into the borehole. The marine riser also allows for the removal and collection of cuttings. As platform operators advance the borehole deeper into the subsurface, mud and cuttings are washed up through the center of the drill bit between the drill string and casing and through the marine riser to the drilling platform. Roughnecks collect the mud/cuttings mixture in special separation tanks. The mud, which is expensive, is recycled and the cuttings are stored for logging and study before they are disposed of onshore. Completion of the borehole and construction of the well to the pay zone—the depth at which geologists expect to encounter oil or natural gas—is done by placing and cementing additional lengths of progressively narrower casing as dictated by the different strata and pressures. Costs for completing an oil well in deep water are in the range of \$100 million up to \$250 million for wells as deep as six miles (10 km).

### **THE DEEPWATER HORIZON BLOWOUT**

On April 20, 2010, the Macondo prospect well (designated MC252 by BP) was near completion, at 18,000 feet (5.5 km) below the seafloor, with cementing of casing finished and planning under way for the installation of a production pipe, a device to collect the oil and natural gas and bring it to the surface. Drilling was five weeks behind schedule, and BP would soon have to start paying \$500,000 a day in extended lease charges. Halliburton, a large multinational oil-service company, was in charge of cementing (grouting) operations.

As 9:45 CDT, the BOP failed catastrophically, and a cloud of methane rushed out of the well, enveloping the rig. Eleven minutes later, the platform burst into flames. The 126 crew members followed their training and abandoned the rig using lifeboats to motor to a nearby service vessel. Helicopters transferred 17 injured survivors to onshore

hospitals and trauma centers. Despite a three-day search, the U.S. Coast Guard was unable to find 11 missing crew members, now presumed dead. They are thought to have been close to the top of the well when the explosion and fire occurred.

The *Deepwater Horizon* burned for almost 40 hours before sinking. At the time of the explosion and fire, BP and Transocean executives were touring the rig to discuss plans for production well operations and to present a safety award for seven years of operation without a lost-time accident. They were not among the injured. There were some reports (vehemently denied by Transocean) that survivors were held incommunicado at sea or in a Louisiana hotel until they could be debriefed by company safety and security specialists.

As is typical in these types of environmental disasters, the responsible parties (primarily BP) at first sought to downplay the potential for major ecological damage from the blowout. Initial statements by BP reassured the press and Coast Guard that very little to no oil was leaking from the damaged wellhead. Based upon data provided by BP, 24 hours later the Coast Guard calculated the flow rate from the uncapped well at approximately 1,000 barrels (159,000 L) per day. This number proved to be a woeful underestimate, and by early July independent experts and government scientists estimated that between 1 million to 2.5 million barrels (159 million to 398 million L) of oil were being discharged from the well every day.

Although numerous investigations are under way, including those sponsored by the federal government, BP, BP's insurers, Transocean, and others, it is clear that a blowout occurred and that the BOP, and its redundant backup systems, failed. The reason for the failure has yet to be determined, but preliminary findings suggest that the BOP may have been damaged during drilling operations.

The response by BP and the government to the disaster began slowly and was disorganized. As oil flowed into the gulf, coastal communities began to complain about a lack of response or preparation from BP and the Coast Guard. Deployment of booms to contain the spread of the spill was delayed, and skimming operations were spotty and ineffective. It took several weeks before the Coast Guard, with help from BP, established a workable, unified response organization. BP stated on more than one occasion that it would take financial responsibility for the cleanup and, after pressure from the White House, set up a \$20-billion compensation fund to pay for the economic consequences of the blowout.

Under the direction and oversight of the Coast Guard, BP developed and implemented a multifac-

eted, creative, and comprehensive approach (subsea, surface water, and shoreline) to the *Deepwater Horizon* disaster. Subsea efforts include:

### Top Kill Procedure

BP attempted to plug MC252 by pumping in a mixture of heavy drilling mud and bridging material (pieces of rubber, golf balls, short segments of rope) through the damaged BOP (which was still attached to the top of the casing) and into the well. Although often successful in shallow water blowouts, this was the first time this procedure was attempted in a deepwater blowout. The effort failed after several attempts and was abandoned by BP and the Coast Guard over concerns that further efforts could exacerbate the damage to the BOP.

### Subsea Containment Structure

BP lowered a 125-ton (113-metric ton), 340 square-foot (31.6-m<sup>2</sup>) dome-shaped vessel (Top Hat) over the top of the well to capture flowing oil and divert it through a riser pipe to surface ships for shipment to shore. However, gas hydrates, crystals of methane similar to ice crystals, formed inside the Top Hat and blocked the flow of oil. BP removed and deposited the Top Hat on the seafloor and evaluated other options.

### Riser Insertion Tube

After the blowout and sinking of the *Deepwater Horizon*, the marine riser pipe, still attached to the BOP, folded over like a bent straw. Oil poured through the end of the now crumpled riser that lay on the floor of the gulf under a mile of water. One of BP's earliest attempts to control the flow of oil was to insert a tube into the end of the marine riser and divert oil to surface vessels. This approach had limited success in capturing oil, but it did collect some oil and gave BP the opportunity to try other containment strategies.

### Lower Marine Riser Package Cap

This containment system was installed after BP removed the damaged marine riser pipe from the top of the BOP. Once remotely operated submersibles sheared off the damaged riser pipe, operators lowered a second pipe onto the BOP and sealed it in place. Using a truly creative engineering solution, BP engineers installed feed lines into the Riser Package Cap to prevent the formation of hydrates. The Riser Package Cap collected and carried oil and natural gas to two surface vessels for processing. This was a major step forward in collecting the oil that allowed BP to continue to explore options to improve the efficiency of oil collection and stop the flow of oil.

### Capping Stack

BP's engineers designed and installed a three-valve, or ram, cap on top of the BOP. The idea behind this device was to close each valve and slowly cut off the flow of oil and seal the well. Under scrutiny of the U.S. Coast Guard, remotely operated submersibles gently lowered the capping stack into position. Once in place, technicians began to close each valve, monitoring pressure readings to ensure that well integrity was not compromised and to prevent another blowout. After 48 hours of continuous monitoring and testing, BP concluded on July 17, 2010, and the Coast Guard agreed, that the cap had worked and no oil was leaking into the gulf from MC252. This was the first time such a system had been deployed successfully at these depths. BP then pumped cement grout into the well, called the static kill, and declared the well shut in, or not discharging any more oil, on July 17. The Coast Guard declared the *Deepwater Horizon* blowout officially under control when BP placed the relief well into service.

### Drilling of Two Relief Wells

Contractors for BP drilled two new oil wells into the Macondo Prospect near the damaged MC252 well—to pump a mixture of cement and grout through the well casing and annular space and finally seal it. Relief well DD3 came within 3.5 feet (1.1 m) horizontally and 50 feet (15.2 m) vertically of MC252 when drilling was halted in order to pressure test the casing and grouting of MC252. Once completed, the relief well was used to reduce the pressure within the same geologic strata in which the *Deepwater Horizon* well was finished and to bottom kill the well. This procedure was completed on September 19, 2010, and the *Deepwater Horizon* well MC252 was declared plugged and abandoned.

BP also attempted to contain the distribution of the oil from MC252 once it entered the surface water system. Techniques used included dispersants, skimming, and *in situ* burning.

### Dispersants

Under the direction of the Coast Guard and with the help of the U.S. Air Force, BP deployed hundreds of thousands of gallons of dispersants into Gulf Coast waters. These chemicals, released from specially designed aircraft, broke the oil into small droplets that dissolved in the seawater and became bioavailable for naturally occurring bacteria and other microorganisms. Dispersants had to be carefully monitored and controlled because, if overused or applied improperly, they can have serious ecological consequences (see *TORREY CANYON OIL SPILL*).



### Open Water Skimming

BP deployed almost 300 commercial skimmers. These specially designed vessels corral and concentrate oil by using floating booms. Once enclosed, oil-skimming pumps remove the tar-like oil into holding tanks for later disposal or reprocessing. For skimmers to be effective, water surfaces must be calm and wind speeds low. BP estimated that it collected approximately 30 million gallons (114 million L) of oil-water mixture, with oil making up about 10 to 20 percent.

### In Situ Burning

In some cases, after skimmer ships collected the oil behind fire-resistant booms, it was set on fire. In order for combustion to be sustained, oil had to be the correct thickness, usually more than one inch (2.54 cm). BP only conducted in situ burning after it received permission from the appropriate regulatory agencies, which monitor weather conditions to ensure that public health and safety is not at risk. Regulatory officials estimate that about 10 million gallons (38 million L) of oil were destroyed via in situ burning.

Despite these and other oil collection and control measures, liquid hydrocarbon from MC252 reached shorelines and fouled beaches in Louisiana, Mississippi, Alabama, and Florida. BP's shoreline protection strategy included the use of booms and onshore cleanup teams.

### Booms

These nonabsorbent, closed-cell polyethylene plastic tubes are designed to float on the surface to prevent oil from washing up on the shoreline. Skimmer ships must patrol regularly in front of the boom to remove oil and other debris that collect against them. Booms typically have about six inches (15.2 cm) of freeboard (area above the surface) to reduce splash over and about 12 inches (30.5 cm) of draft or curtain (area below the surface) to divert underflow. Booms come in varying lengths and are joined by quick-connecting lengths of galvanized chain or rope. Using emergency response contractors and local ships with special health and safety training in its Vessels of Opportunity program, BP deployed hundreds of thousands of feet of booms along the Gulf Coast shoreline. The booms had varying degrees of effectiveness, depending upon weather and wave conditions. Many local communities complained that BP was slow to deploy the booms, despite repeated, often frantic, requests.

### Onshore Cleanup Teams

BP hired and trained more than 15,000 workers to remove oil from Gulf Coast beaches. These workers

used shovels and heavy equipment (front-end loaders and graders) to collect and remove oil-contaminated sand for processing and disposal. Depending on the extent of beach oiling, they constructed sand berms to prevent the further onshore flow of oil, or they collected by hand individual "tar balls" that washed ashore. This last line of shoreline defense was less effective in recovering oil from the thousands of isolated bayous, inlets, and channels that dot the Gulf Coast and serve as habitat for large numbers of birds, mammals, and reptiles.

### MEDIA COVERAGE

Although catastrophic, the *Deepwater Horizon* blowout is not unique. In early June 1979, near the Bay of Campeche, Mexico, a catastrophic blowout occurred at the oil production well *Ixtoc I*. Over the next 10 months, an estimated 140 million gallons (530 million L) of oil leaked into the Gulf of Mexico. Thirty years later, beachcombers and divers still can find asphaltic residues from that spill on beaches and reefs along the Mexican and U.S. coastlines. Ten years earlier, an oil well blowout near Santa Barbara formed an 800-mile (1,288-km)-long slick and killed more than 4,000 seabirds.

The *Deepwater Horizon* blowout is the most well-publicized environmental disaster of all time. Advances in technology and the presence of the Internet allowed the viewing of oil spewing out of the well and the remotely operated submersibles working a mile (1.6 km) deep through the "oil cam," a series of underwater cameras. This high level of visibility greatly increased pressure on elected officials and BP to mobilize needed spill-response resources. During the 85 days before BP was able to cap MC252, President Obama visited the Gulf Coast four times, responding to claims that his administration was not acting quickly enough and reassuring residents that the federal government was engaged proactively in cleanup efforts.

BP and federal agency officials did not place restrictions on media coverage, except as it related to the safety and privacy of response workers and the effectiveness of oil-recovery activities. Correspondents were able to roam beaches and observe how the cleanup progressed, film skimming and controlled burning operations from charter boats, and freely question BP and government representatives during regular press briefings. There were several incidents of BP security personnel and local police briefly detaining, questioning, and allegedly attempting to intimidate reporters, but these seemed to be infrequent, isolated occurrences. BP also undertook a very polished public relations campaign, using radio,

television, the Web, and print ads to publicize its efforts to clean up the spill and rehabilitate its image.

### ECOLOGICAL DAMAGE

The failure of the BOP at MC252 has been compared to the release of 11 million gallons (41.6 million L) of oil from the *Exxon Valdez*. However, researchers and scientists must use caution in attempting to rely on the ecological damage caused by the *Exxon Valdez* spill as a benchmark for effects that may be related to the *Deepwater Horizon* blowout. There are more differences between the two spills than there are similarities.

Prince William Sound, where the *Exxon Valdez* disaster took place, was relatively ecologically pristine compared to the Gulf of Mexico, which has a number of well-documented, modern-day pollution problems (see DEAD ZONES, for example). The ecosystem of the Gulf of Mexico is commonly exposed to oil, with natural seepage from subsurface geologic formations alone possibly releasing up to 165,300 tons (150,000 metric tons) annually. Native Americans living along the Gulf Coast used oily tars produced by this seepage in pottery and waterproofing since prehistoric times. Although natural oil seepage may have allowed for some adaptations by Gulf Coast organisms, these would be overwhelmed by the amount and speed of the MC252 release.

The ratio of the volume of oil released by the *Exxon Valdez* into the water in Prince William Sound was much higher than in the *Deepwater Horizon* spill. The *Exxon Valdez* spilled fresh, highly toxic oil directly on ecologically sensitive areas, whereas the *Deepwater Horizon* leaked oil in the open ocean, where it degraded to a much less toxic form before reaching the coast. The movement of oil within the sound, which is only 45 miles (72.4 km) wide, was more restricted than in the larger gulf, and as a result it did not spread as far. Climate also played a key factor in how the Alaskan ecosystem responded to the oil. With short summers and very severe winters, oil movement and degradation is slower. The oil from the *Exxon Valdez* had an extended residence time within the environment that likely magnified its impact, whereas Gulf Coast waters and air temperatures are warmer and more quickly degraded and dispersed the oil.

Despite these and other differences, scientists and policy makers used ecological effects from the *Exxon Valdez* as a rough set of precursors for the ecological damage likely to occur because of the *Deepwater Horizon* event. MC252 blew out at the beginning of the gulf's peak spawning and nesting

season for numerous varieties of fish, birds, and sea mammals. At particular risk are the brown pelicans, Ridley and loggerhead sea turtles, whales, and coral reefs. Effects to these creatures will be severe for many years to come. Higher-level organisms that rely on shrimp and crustaceans, which form the base of the Gulf Coast food web, either will die off or be forced to abandon Gulf Coast waters for new hunting and foraging areas. Neither the government nor BP has published an estimate of animal fatalities, but using the Prince William Sound effects as a guide, they likely will be in the many thousands. Within weeks of the release, volunteer animal rescue groups were reporting hundreds of sick and dead birds and marine mammals and fish washing up on beaches and floating in coves and bays.

Fisheries will take several years to recover and, as is claimed by many local fishermen at Prince William Sound, may never return to pre-spill numbers. Vegetation along the coastline will fare better. Depending upon how heavily oiled, they are projected to return to their pre-spill levels within three to five years. The animals relying on that vegetation for food and habitat will be displaced or greatly distressed during this time. Despite the billions of dollars being spent on oil recovery, ecological damage in the gulf will be extensive and long-lasting.

One important factor that researchers take into account in assessing long-term ecological effects from MC252 is the presence of a dissolved layer of hydrocarbons detected below the water's surface within the gulf. Although oil is less dense than water and does not readily mix with it, this usual chemistry is only applicable within a narrow range of pressure and temperature. The millions of gallons of oil, much of it containing high concentrations of dissolved methane, 5,000 feet (1.5 km) below the surface interact differently with seawater than does oil at the surface. Scientists measured a 30-mile (48-km)-long lens of dissolved oil seven miles (11 km) wide and hundreds of feet thick near MC252. No one is sure how long this lens will remain intact and what the ecological implications of its presence are. One result is that the carbon in the oil may serve as a nutrient source for the growth of microorganisms that consume dissolved oxygen in the seawater. Indeed, lower oxygen levels were found in the area of the plume. Eventually, this could create a large "dead zone," similar to that farther north at the mouth of the Mississippi River. The widespread use of dispersants that chemically encourage oil to dissolve and mix with seawater could compound this effect.

Unlike the Mexican government response after the *Ixtoc I* blowout in 1979, BP has created a substantial

research fund to study and quantify the ecological effects the MC252 spill has had and will have on Gulf Coast ecosystems. These studies, combined with long-term government-run monitoring programs, will form the basis for a restoration plan that will support and enhance nature's own recovery efforts within this critically important water resource and habitat.

### REASONS FOR THE BLOWOUT

It will be years before engineers and safety experts are able to assemble a definitive explanation of the events onboard the *Deepwater Horizon* that led up to the blowout. However, the causes probably will be directly or indirectly related to several factors.

1. One of the most egregious reasons for the blowout is the failure of federal regulatory agencies, particularly the now-defunct Minerals Management Service (MMS), to provide consistent and effective oversight and enforcement of the permits it issued to the operators of the *Deepwater Horizon* as well as the MMS's own deep-water drilling regulations. Congressional hearings shortly after the blowout strongly emphasized this failure and ridiculed MMS-approved spill-response plans of companies for including procedures to protect walrus, which do not inhabit the Gulf of Mexico, and containing emergency contact information for a scientist who had died several years ago. MMS appears to have become a "rubber-stamp" for oil company drilling operations in the Gulf of Mexico.
2. Complementing the regulatory failure was BP's inability or unwillingness to insist that its subcontractors and vendors hold paramount the health and safety of its workers and the protection of the environment. This obligation, which BP espouses as one of its core corporate values, apparently was not part of the *Deepwater Horizon*'s operational culture. Early, unconfirmed post-blowout reports have described several events when BP executives placed significant pressure on *Deepwater Horizon* staff to continue to drill, even as roughnecks and platform engineers began to express serious concerns about the functional capability of the BOP and stability of the borehole. These accounts take on added credibility considering the 2005 industrial accident at a BP refinery in Texas City, where an explosion killed 15 workers, all subcontractors, and was caused by a faulty and poorly operated venting system. The Occupational Health and Safety Administration, OSHA,
3. Transocean, the operator of the *Deepwater Horizon*, is also held accountable for the blowout. Their adherence to safety appears to have been relaxed when BP, a major customer, applied contractual pressure. Unconfirmed post-blowout reports by Transocean staff described a pattern of behavior by senior Transocean managers of discounting safety concerns if they interfered with drilling or well-completion operations. News reports quoted surviving Transocean employees describing a company culture where safety was important but not important enough to threaten the bottom line.

The causes of the *Deepwater Horizon* blowout will be studied, litigated, and debated for years, but this process will not last as long as the ecological and economic damage caused by releasing more than 204 million gallons (772 million L) of oil into the Gulf of Mexico—the worst environmental disaster in U.S. history.

See also DEAD ZONE; EUTROPHICATION; EXXON VALDEZ OIL SPILL; IXTOC I OIL SPILL; OFFSHORE OIL PRODUCTION; OIL SPILLS; ORGANIC POLLUTANTS; PIPER ALPHA OIL SPILL; SANTA BARBARA OIL SPILL; TORREY CANYON OIL SPILL; WATER POLLUTION.

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**delta** A delta is the feature that is produced where a river enters a low-lying area called a receiving basin, be it the ocean, a lake, or any other standing body of water. A delta is formed when a river or stream has a generally unidirectional flow that is strong enough to carry sediment and enters a body of water that has no flow or whose flow is contrary to the river. The slowing to stoppage of flow causes the carried sediment to deposit at the mouth of the river. Depending upon the volume of sediment and the flow rate of the water being discharged into the receiving basin, different delta shapes or geometries are possible: bird's-foot, lobate, semicircular, or the classic  $\Delta$  with the tip pointing upstream. There is a general division between delta types as constructive or destructive; constructive deltas are those formed in a low-energy basin, and destructive deltas those formed in a high-energy basin. *Constructive* means that new land is formed as the result of the process, and *destructive* means that no new land is formed. Each type has different environmental issues, depending upon the processes that formed it. Most deltas share the problem of poor water quality in the river. Most cities situated along a river remove water upstream of the city and release wastewater downstream of the city. It is said that the water in the Mississippi River, for example, is used and reused six times before it arrives at New Orleans.

### BIRD'S-FOOT DELTA

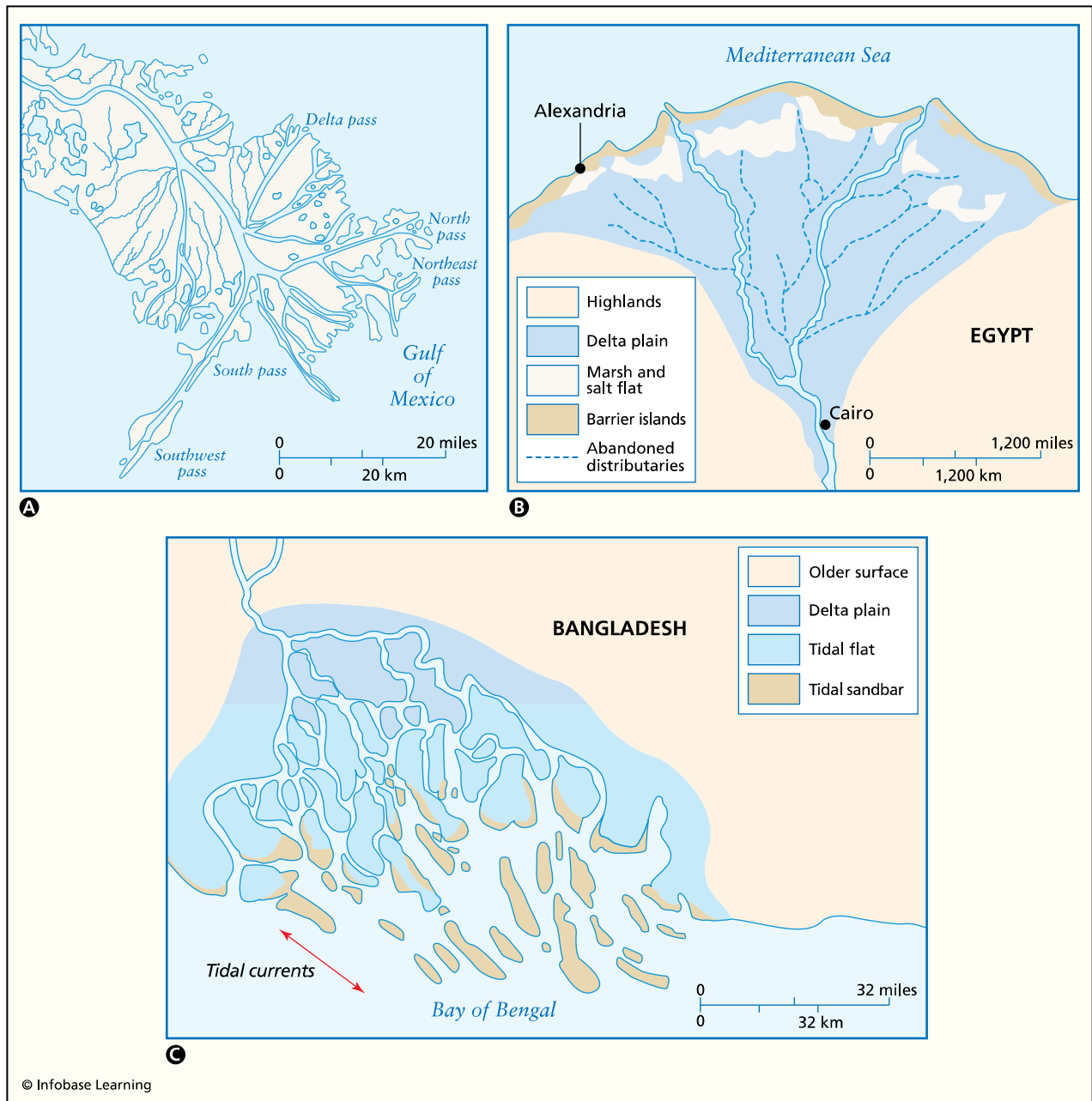
A bird's-foot delta is the most constructive type of delta. It requires extremely low-energy (small waves and tides) receiving basins to form. The best example of a bird's-foot delta is the Mississippi River delta in the Louisiana part of the very low-energy Gulf of Mexico. The low energy allows all deposits, both sand and mud, to be preserved. Bird's-foot deltas have a single main distributary channel, where virtually all of the activity takes place. Where the water from the river impacts the basin water, the flow slows abruptly but penetrates into the basin in a jet that may extend several hundred feet or more

past the end of the delta. This process causes massive amounts of sand to deposit right at the mouth in a distributary mouth bar, and progressively finer sediment deposits farther into the basin. With time, the channel cuts through the mouth bar, causing it constantly to shift basinward. This downstream movement of the mouth bar, called a progradation process, causes the mouth bar sand to be deposited over previously deposited (prodelta) silt, which is, in turn, deposited over prodelta marine clays. Therefore, the size of the sedimentary grains present in deltaic deposits becomes larger (coarsens up) closer to the present-day ground surface. As a result heavy sand is deposited over soft and weak clay, an unstable situation.

The growth of a bird's-foot delta involves the formation of levees composed of mouth bar sand covered by overbank deposits. Long thin strips of land containing the channel extend far into the receiving basin, stretching along the length of the river. The farther the river extends into the receiving basin, the more back pressure is exerted on the flow. At some point, commonly during flood conditions, this back pressure causes the river to break through levees at a weak or thin spot, and a splay forms. If the splay is small, it may just form a small delta off the main distributary channel. If the splay is large, the whole river may shift into this new channel, abandoning the old channel. Over time, this process of shifting channels spreads the delta out, creating a significant landmass. Where channels wrap around parts of the receiving basin, small bays form between the channels. These interdistributary bays may develop into lakes in some cases. The huge Lake Ponchartrain to the north of New Orleans was formed in this manner.

Environmental issues abound in bird's-foot deltas. The land is primarily composed of heavy sand resting on weak mud and silt, producing a gravitationally unstable situation. As soon as active sedimentation from the river shifts away from an area, the land immediately begins to sink into the underlying mud, and subsidence ensues. Hundreds to many thousands of acres of land may slowly sink below sea level and into the marine basin each year, depending upon the size of the delta. The constant shifting of the delta's distributary channel makes land management very complicated. Those deltas that form by rivers' emptying into the sea or ocean, such as the Gulf of Mexico, produce a constant threat of saltwater incursion. As the land subsides, salt water begins to mix and contaminate the freshwater from streams and rivers. The surrounding salt water also infiltrates the underlying groundwater system, making it nonpotable. In addition, lower ground





**Maps showing three types of deltas. Highly constructive “birds’-foot” delta of the Mississippi River as it enters the Gulf of Mexico in Louisiana (A); the classic constructive lobate Nile River delta in Egypt as it enters the Mediterranean Sea (B); the destructive tide-dominated Ganges-Brahmaputra River delta in Bangladesh as it enters the Bay of Bengal (C)**

elevations increase the risk of flooding and damage from coastal storms.

Typically on bird’s-foot deltas, the only source of freshwater is that supplied by its rivers and streams. This surface water system is very sensitive to spills and leaks from industrial operations and local waste treatment and disposal facilities. These spills and leaks can be rapidly distributed by the intertwining and connected nature of the delta’s surface water

system and compromise community water supplies throughout the delta.

The shifting nature of the streams and rivers operating within a bird’s-foot delta also make water supply planning difficult. If the river shifts, water supply intakes that once were fed by a stream or river suddenly run dry. There is no freshwater for the inhabitants downstream, and expensive public works projects must be designed and implemented

either to provide alternate water supplies or to reroute the stream or river that had been acting as the freshwater supply.

The discontinuous and episodic way sediments are deposited in a bird's-foot delta leads to large areas where there is only limited exchange of water between supply streams and the areas between channels. This results in the development of large zones of stagnant water in the vast swamps that are common to bird's-foot deltas. These can be breeding grounds for disease-carrying insects (vectors) and the source of illnesses such as malaria and typhus.

Finally, in tropical and semitropical regions because of the low elevation of bird's-foot deltas and their being surrounded by water, they can be more adversely impacted by coastal storms and hurricanes than higher-elevation, more geologically stable inland areas. The high winds and storm surge associated with Hurricane Katrina contributed to the failure of the levee system designed to protect New Orleans from flooding. It was these floods that devastated the city, killed hundreds, and resulted in the need for an expensive and massive rebuilding effort.

### LOBATE DELTA

Lobate deltas are also constructive but produce less new land than bird's-foot deltas. Lobate deltas were the source of the name *delta*, which was based upon the similarity of their shape to the Greek letter. The distributary channel enters the upstream apex of the delta and splits into a fan-shaped geometry of diverging (radiating) channels. One or more of these channels are active at any given time, and the active channels constantly shift back and forth across the delta. With sediment being continuously delivered to the receiving basin, the flat side of the delta against the basin grows into the basin, thus increasing the amount of land along a continuous front.

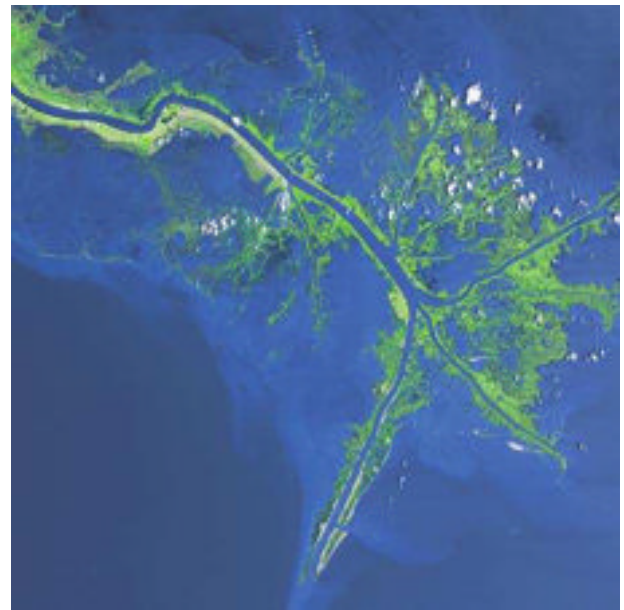
The reason that each active channel does not grow as in a bird's-foot delta is that the energy of the receiving basin of a lobate delta is higher than that of a bird's-foot delta. Wave energy is typically the reason. It spreads out the sediments across the front of the delta primarily through longshore currents. The classic lobate delta was the Nile River delta in Egypt. The building of the Aswan Dam, however, reduced the sediment supply enough to disrupt replenishment of the basin side of the delta, and it has been shrinking ever since. Under its strict definition, this would qualify it as a destructive delta.

The environmental concerns related to a lobate delta are generally similar to those of a bird's-foot delta. Saltwater incursion can be a problem, as can

pollution of the extensive surrounding wetlands. The lobate delta is typically very fertile and used extensively for agriculture. The release of fertilizers and pesticides into the river either from direct spraying or from runoff compromises the quality of the river water. Nitrates can cause increased biologic activity and low oxygen conditions, which result in fish kills and other problems. Irrigation and damming of the river can cause reduced sediment supply and the loss of land.

### TIDE-DOMINATED DELTA

In basins where tidal reach is high, rivers may become flooded, producing a distinctive tide-dominated delta within an estuary. The sand bodies are elongated in a tide-dominated delta and lie perpendicular to the coastline within the river mouth with a digitate appearance. High tide causes ocean water to be driven up the river up to several tens of miles. In the main river, the flow of the river reverses. This flow cuts tidal channels in the delta. During these conditions, the sand bodies are typically completely submerged. When the tide turns, water flows back down the river and through the channels. The sand bodies become land at this time. There are a distinctive group of sedimentary structures produced in these areas as a result of the reversing flow directions and submergence and emergence of the land.



False-color image of Mississippi Delta recorded by NASA's *Terra* satellite off the southern Gulf Coast in May 2001 (Image provided by USGS EROS Data Center Satellite Systems Branch as part of the *Earth as Art II* image series, NASA)

Environmental issues in tide-dominated deltas primarily involve saltwater incursion. The water in the whole lower portion of the river is typically brackish and nonpotable. Residents must obtain other sources of freshwater. The brackish water enters the groundwater system near the river, and pumping wells must be carefully monitored to prevent them from drawing it under heavy pumping or drought conditions. The interaction of freshwater and salt water can result in the formation of unexpected compounds. Certain species may be soluble in freshwater but precipitate if exposed to salt water. This is not a problem in natural systems, but if wastewater or other pollutants are added to the freshwater of the river, the chemistry of the system may be altered. The pollution may not be only from the freshwater source but also from salt water. Oil spills and waste disposed of at sea may return upstream to inhabited areas during rising tides. Tidal areas also tend to be swampy and may harbor disease, especially that which may be carried by mosquitoes.

### WAVE-DOMINATED DELTAS

For most rivers entering the sea, the wave energy far exceeds that of the river flow. The waves spread the sand and coarser material along the coastline in a beach and carry the fine material into deeper water. There is no real delta formed as in the other types, but instead the river empties into a beach, which represents the sand bodies. No new land is made, but the existing land is modified in its content of sand.

Environmental problems in a wave-dominated delta are similar to those at a beach. Waste washing up onshore, oil spills, and saltwater spray and incursion are some of the more common problems. The fragile ecosystem of a beach and lack of buffered transition zone between marine and nonmarine conditions make these areas particularly prone to problems caused by pollution and building.

See also BEACHES; CONTINENTAL SHELF; TIDES; WATER POLLUTION.

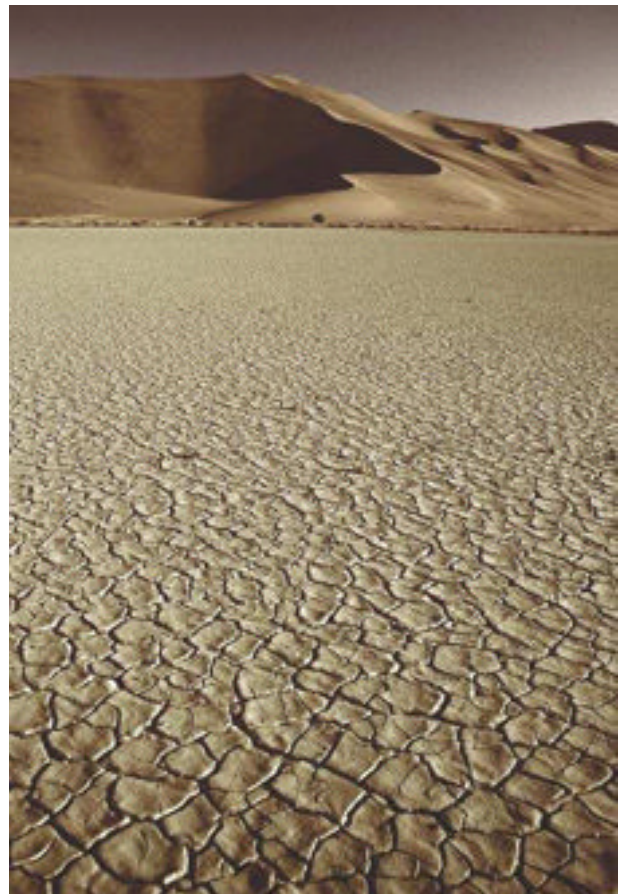
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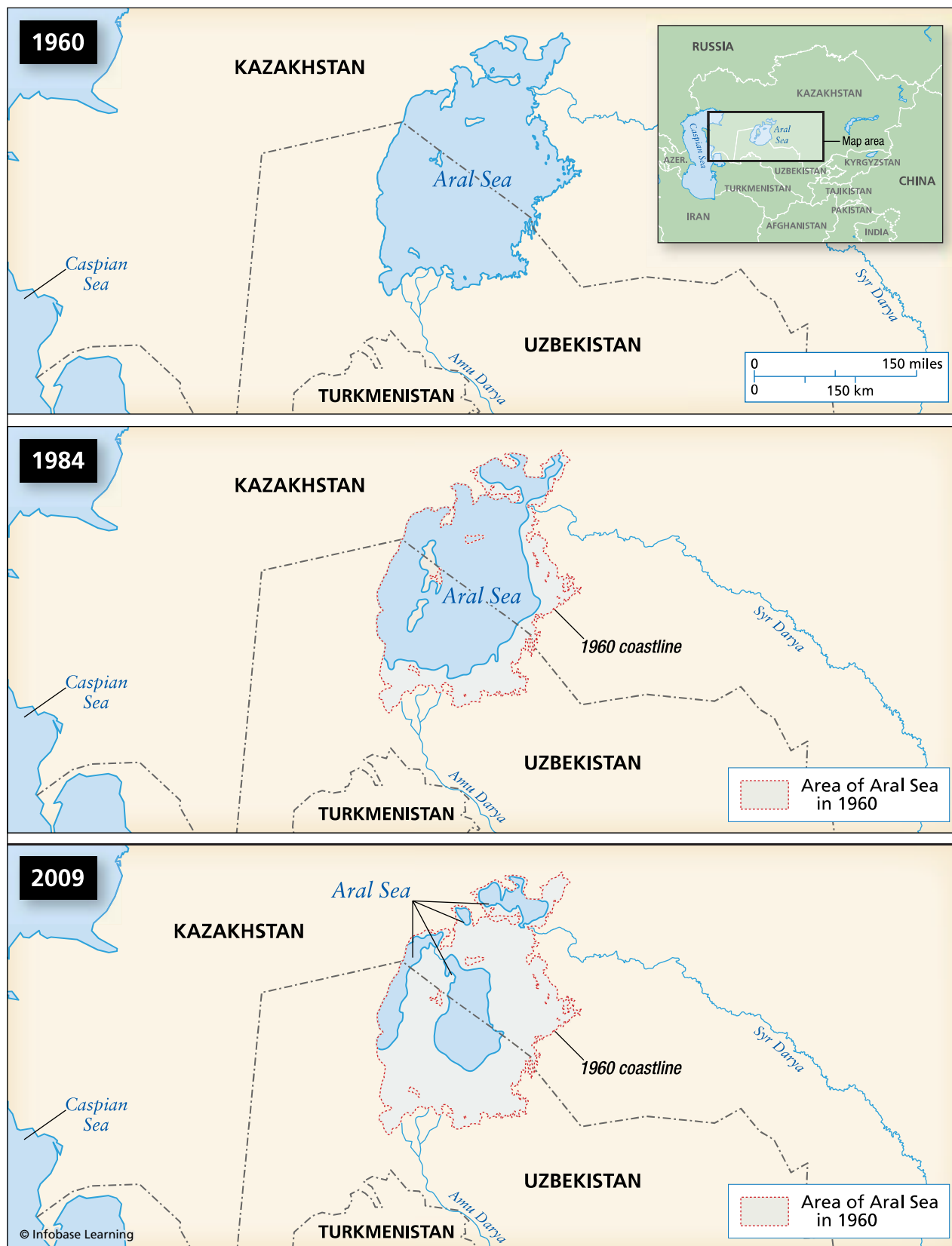
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**desertification** The original definition of desertification was the spread of existing deserts into surrounding productive areas. Since then, the term has evolved into a more general conversion of any productive area into desert conditions. Certainly, desertification can be a natural process in response to climate change from wetter to dryer conditions. A major environmental concern, however, is the rapid expanse of desertification on a worldwide basis as a result of human activity. The main causes of desertification are overgrazing of domesticated animals and deforestation in areas marginal to deserts, adverse soil erosion, poor drainage of irrigated lands, poor farming techniques, overuse of water supplies, and human-induced global warming. Desertification does not occur in a continuous front in most cases but instead advances in patches that expand in an inconsistent ebb and



**Mud cracks in a dry-river bed in Soussesvlei, Namibia**  
(Geof Kirby/Alamy)



Maps showing the successive shrinking of the Aral Sea in the Soviet Union and former Soviet Union in 1960, 1984, and 2009. The water was withdrawn for irrigation at a rate faster than it could be replenished. The new dry land is desert, resulting in desertification of the area.



flow. Africa has experienced a huge loss of productive land as the Sahara spreads southward at alarming rates. This situation is largely blamed on overgrazing, which removes the stabilizing properties of the plant roots, but certainly climate change is also a contributing factor. Another poignant example is the Aral Sea in southern Russia. As the result of overuse of water from the Aral Sea, largely for irrigation, it has shrunk to one-third its original size, and the area that was formerly water is now desert. (There is a striking photograph of a fishing boat embedded in sand as far as the eye can see with the words “Forgive us, Mother Aral” scrawled in Russian across the side.)

Desertification causes pollution of soil, water, and air. Sand is blown from the exposed surface onto otherwise productive land, polluting the soil. The additional sand and dust slowly render the soil unproductive. In other cases, fields of sand dunes migrate over productive areas and literally drown the productive soil in sand. Soil with no vegetation and open sand are also much more prone to erosion during precipitation events, which can choke streams with sediment, compromising the water quality. Wind lifts dust off the desert surface, affecting air quality with particulate as well. Devastating dust storms that are common around deserts can cause severe health effects, but the effects can be much more widespread. Windblown dust from deserts has been documented to cross the Atlantic Ocean from Africa to the Americas on a regular basis and even, on occasion, to cross the Pacific Ocean from China to North America.

**deserts** Deserts are regions where the annual rainfall totals are less than 10 inches (25 cm) of precipitation per year. It is a common misperception that deserts must be hot, but only tropical deserts fit this definition. For example, the polar regions are also deserts. They may contain frozen water at the surface, but the amount of precipitation is low and the accumulation rate is extremely slow. They also may be the most harshly polluted relative to the sensitivity of the environment.

### LOCATION OF DESERTS

Most deserts of the world are at 30° north and south latitude and at the Poles. The circulation system of the atmosphere controls these locations. If air falls or is driven toward the surface, the downward force creates a higher air pressure. If the air rises, the upward force creates lower air pressure. High pressure means clear sunny weather, whereas low pressure means cloudy, stormy weather. The reason for this pattern is that air is normally warmer at the

surface and can carry a lot of moisture. As it is swept upward, it cools and the moisture condenses into clouds and precipitation. Air from higher altitudes in the atmosphere is cool and dry. As it falls, it warms up; that means that it has even less moisture than it can hold. It takes a predominance of high pressure on a long-term basis to form a desert.

The Sun is more direct at the equator, and, as a result, the air is warmer and rises. Rising air creates precipitation, and thus the tropical rain forests are located in a band around the Earth at the equator. The Sun is least direct at the Poles, and as a result the air is cooler and falls. The resulting high pressure there is the reason that it is a desert. This equator-to-Pole circulation would form the single circulation cell in each hemisphere if it were not for the rotation of the Earth. The twisting of the atmosphere caused by the Coriolis effect subdivides the single large cells into three smaller Hadley cells. The subdivisions mean that air also rises at 60° north and south latitudes, creating temperate rain forests, and it falls at 30° north and south latitudes, thus creating the deserts of the world.

Other effects may also produce small deserts. If air is forced to rise up a hill or a mountain that is in the way of the weather flow, it is just as if it were rising in a low-pressure system. As it rises and cools, the water vapor in it condenses and it rains all of the moisture out on the slopes of the mountain. As this air continues over the mountain and descends the slopes on the far side, it is the same as if it were falling in a high-pressure system. The dry, cool air heats up, so that it can carry more moisture rather than less, and there is no precipitation. The precipitation on the wet, rising air-side of the mountain is called orographic precipitation, and the dry, falling-air side of the mountain is called a rain shadow. The best example of this occurs in Washington State, where the west side of the Cascade Mountains is a temperate rain forest in large part because of the orographic precipitation. The east side of the Cascades is a desert because it is in a rain shadow.

In order to be able to generate precipitation, there must be surface water for evaporation to take place. In areas where there is all landmass and no ocean, there is very little rain. It is unlikely that technically a desert can be formed purely because of the lack of surface water, but it can be very dry at all latitudes. In these areas, deserts can stretch much farther than usual from 30° north and south latitude lines.

### SEDIMENT TRANSPORT

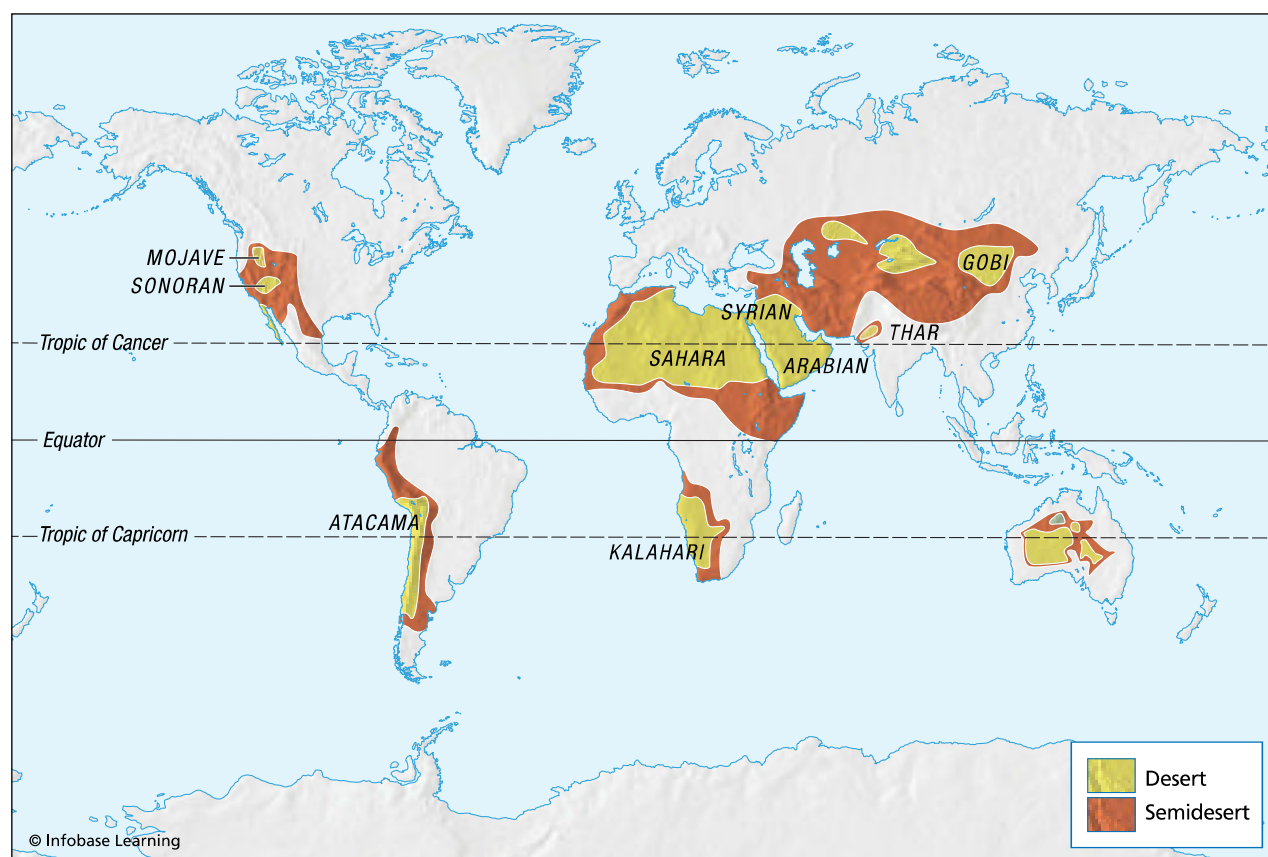
The main differences between erosion and transport of sediments in temperate regions and those in a

desert are vegetation and moisture. In temperate regions with moderate rainfall, both of these factors serve to stabilize the sediment. In deserts, the sediment is used as an effective mechanism of enhanced erosion. The regular daily erosion is primarily accomplished by wind. Unfettered by such sources of friction as trees, houses, and other obstructions, wind can relentlessly sweep over the landscape at high velocities. As in transport in streams, the wind carries sediment in suspension, by saltation (bouncing off the ground surface), or by rolling it along in the surface load. The suspended load is made up of dust and silt and can be carried aloft at heights up to one mile (1.6 km) and spread tens to hundreds of miles downwind of the source region. In some cases, the dust can be transported thousands of miles out of its source region. For example, dust from Africa is commonly found blown all the way to North America across the Atlantic Ocean. This dust is part of the particulate measured in air pollution studies.

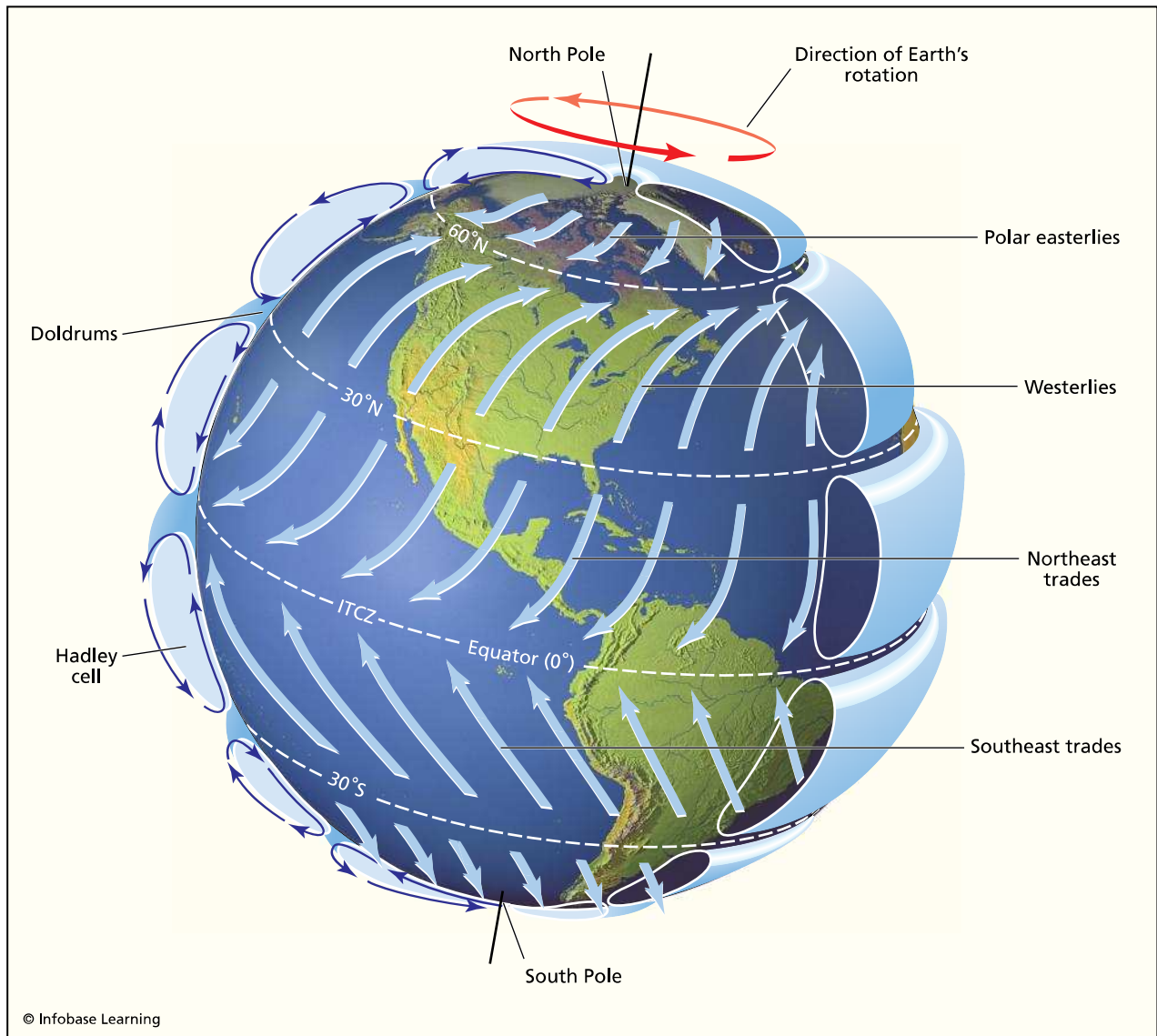
The sediment moved in saltation is also part of the surface load. These generally sand-sized grains bounce as they are transported in the wind. Their travel path is generally a series of arcs whose shape depends upon the substrate. They tend to jump about

20 inches (50 cm), but they can rise up to 6.5 feet (2 m) if they bounce off a hard surface. The sand is driven so hard by the wind that it can strip the paint from a car or facet a rock. The rolling sediment is pebble or larger size and cannot be lifted from the surface. In cases where the wind is strong enough to move everything smaller than the pebbles, it can move the finer sediment in a deflation structure and leave a lag deposit of pebbles. The surface pebbles can be fitted and set together and polished by the wind, forming desert pavement. The exposed larger grains are polished flat on the wind side. A multifaceted rock is called a ventifact.

Sand can also be carried by water during the infrequent desert storms. As with the wind, there is much less friction in a desert. Runoff and surface water flow very quickly and form sheet washes and flash floods in the ephemeral streams. The sediment is more readily suspended in the flowing water in a desert because of the velocity and turbulence, but suspension primarily occurs because the sediment is not fixed to the surface as in temperate regions. The entrained sediment makes the flowing water much denser but also a much more effective agent of erosion than clear water. The floods cut deep, steep-walled channels into the desert



Map of the world showing the locations of the major deserts, primarily centering around 30 degrees north and south latitude



**Earth's major atmospheric circulation cells (rotating arrows). Where air rises at the equator and 60 degrees north and south latitude, there is low pressure and consequently plentiful precipitation. Where air falls at 30 degrees north and south latitude and both North and South Poles, there is high pressure and consequently very little precipitation.**

that are dry most of the time. They are called dry washes or arroyos.

### EROSIONAL FEATURES

The heavy wind erosion and intermittent water erosion are strong agents of change for the desert landscape. The sandblasting readily abrades most rock surfaces. Softer materials such as shale weather quickly, whereas more resistant layers do so slowly. It is this contrast in resistance erosion of the different rock types that creates the desert landforms. In areas of flat-lying strata, erosion will progress through layers in depth order. If a less resistant layer

is encountered, erosion will proceed much more quickly. The contrast between the more resistant layers on top and softer layers beneath results in a step pattern from the flat resistant layer with a cliff in the softer layer and a deeper flat area in the next resistant layer down. Erosion proceeds on this feature as wind abrades the softer layer away until the resistant capping layer is undermined and collapses. Slowly, the capping layer erodes away until the landscape height is reduced.

The step-pattern landscape evolves into other characteristic features. If erosion proceeds around the flat area so that it becomes a raised flatland surrounded on two or more sides by a cliff stepping

down, the flat area is called a plateau. As erosion reduces the size of the flat top, it becomes a mesa, a small table-shaped feature with cliffs on all sides. As erosion proceeds, the feature shrinks to a pinnacle or chimney before it erodes away completely. In some cases, two chimneys may still contain a flat slab of caprock across the top. These are called arches. There are other erosional forms such as yardangs, which look like small shrubs with a larger, flat piece of caprock perched atop a thin pinnacle. All of these, however, are just left-over pieces in the grand erosional scheme.

The resistant caprock does not need to be flat lying. It may be tilted in one direction, and, if so, it will erode into another group of structures. For gently inclined strata, there will be a gentle slope on the caprock and a steep slope instead of a cliff. This feature is called a *cuesta*. If the strata are steeply inclined or even vertical, the resistant layer forms a spine, with the weaker layers and rubble or talus forming lower sides. This feature is called a *hogback* because of the resemblance in appearance.

### DUNE FORMATION AND CLASSIFICATION

Probably the most identifiable feature in deserts is the sand dune. These features are piles of sand that have been shaped by wind movement. Sand dunes are initiated on some obstacle to wind flow such as a rock or a shrub. Although the front side of the obstacle experiences high wind velocity, some sand can become trapped beneath it. More sand builds on the obstacle until it buries it in a crescent-shaped dune that can move away from the obstacle in the downwind direction. The dune has gently inclined slope on the upwind, or *stoss*, side of the dune and a steeper slope on the downwind, or *lee*, side of the dune. Sand is carried up the *stoss* side of the dune, which is eroded by the high-velocity wind. Once the sand reaches the top of the dune, it slides down the *lee*-side slope, called the *slip face*. This side is protected from the wind, forming a shadow. The sand accumulates on this side of the dune.

It is this process of eroding sand from one side and depositing on the other by which dunes migrate. The shape of the deposited layers of sand on the *slip face* is originally asymptotic both on the top and on the bottom. During migration, however, the top of the *slip face* deposit is eroded as the *stoss* side migrates over the top of it. The final shape of the *slip face* deposit is sharp on top but asymptotic on the bottom. These deposits left by migrating dunes are called *cross beds*. The *slip face* deposits are called the *foreset beds* or *layers*, and the flattened-off top is called the *topset*. The Navajo Formation sandstones

in the southwestern United States have the best desert-dune-generated cross beds in the world. They are used as illustrations in many textbooks.

Depending upon factors such as velocity of the wind, direction and stability of directions, sediment supply, and grain size, the dunes can take on a number of shapes. Probably the most common of these is the Barchan dune, which retains the shape of the original formation on the obstacle. These dunes are crescent shaped with the two pointed tips pointing in the downwind direction. They are common in areas of flat topography, a single constant wind direction, and limited sand supply. If the wind direction shifts periodically to several directions, a number of Barchan dune shapes will coalesce into a multiply pointed star dune. Where there is an ample supply of sand and only moderate winds in a single direction, large transverse dunes develop. In contrast to the curved shape of a Barchan dune, transverse dunes have long straight crests like ocean waves. If the winds increase in velocity, the straight crests bend and break, forming a crescent to horseshoe shape similar to that of the Barchan dunes called Barchanoid dunes. In very high-velocity winds with ample sand supply, the sand bodies stretch out parallel to the wind direction in thin elongate ridges. These are called longitudinal dunes, or *seif* dunes, from the Arabic word for “sword.” These dunes can reach heights of 325 feet (100 m) and extend in length for several miles. There is one thick sand area in Saudi Arabia called Rub al Khali, where the *seifs* reach 975 feet (300 m) high and stretch for almost 120 miles (192 km). The final type of dunes are parabolic dunes and are also similar to Barchan dunes but with the tips pointing upwind instead of downwind. They are backward relative to wind direction and form in areas where there is enough vegetation present to affect the dune shape. Most dunes are more commonly 100 feet (30 m) in height, but transverse to parabolic *draas* dunes in Saudi Arabia may reach heights of 820 feet (250 m) with wavelengths of two-thirds of a mile (1 km) or more.

### POLLUTION OF THE DESERT

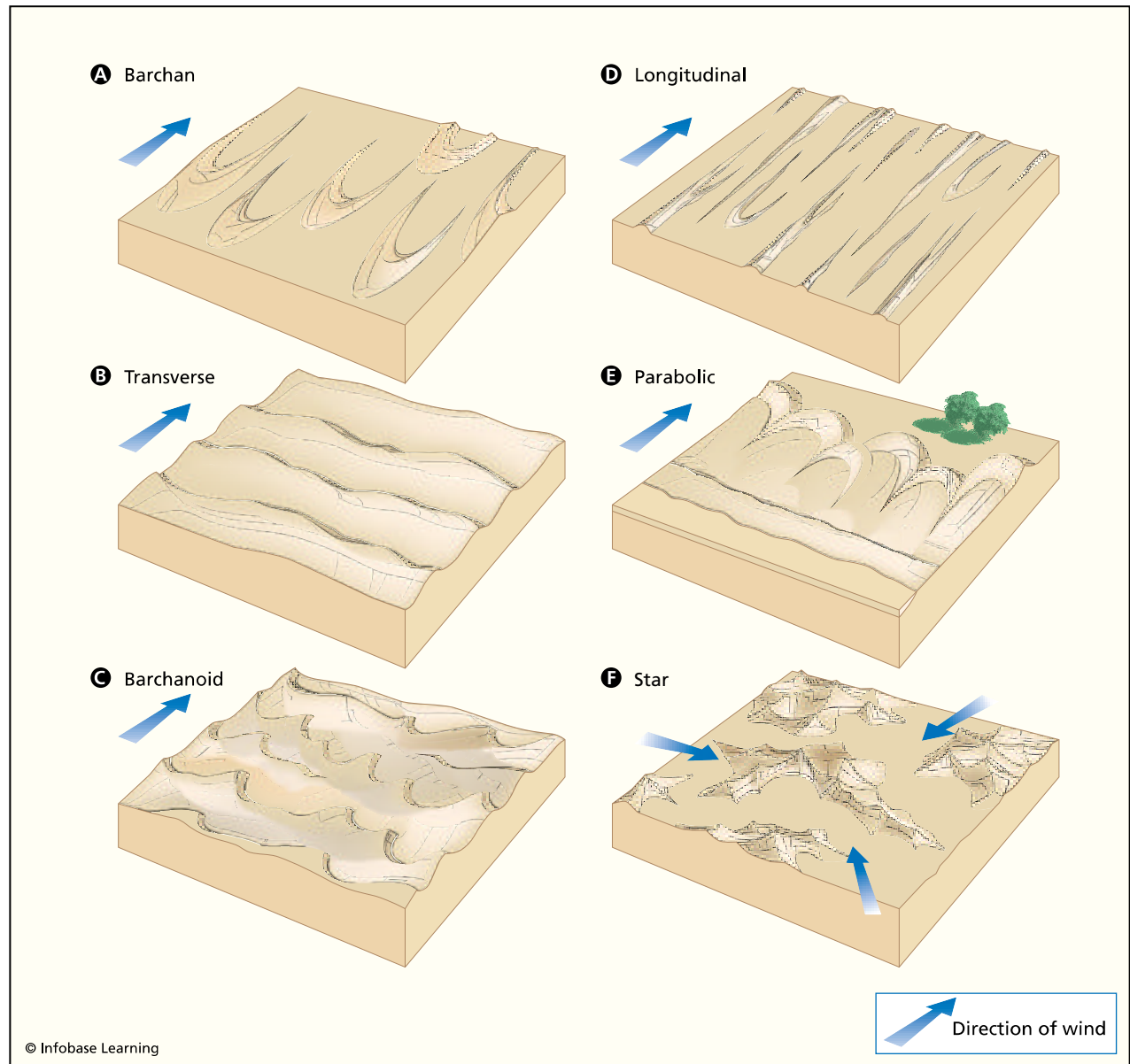
There is some natural pollution in the desert. All of the dust in suspension is particulate made of fine quartz grains. Even in the natural state, inhaled fine quartz can scar the lungs, causing the disease called *silicosis*. This is by far the most dangerous health threat in a desert. Besides this air pollution, there is also some water pollution. With the intense amount of evaporation, any ions in the surface water are quickly concentrated and precipitated as salts onto the sediment. In some cases, calcite may be



precipitated just below the surface to form caliche. In most cases, the precipitants are halite, gypsum, and borax, among others. During subsequent rainfall events, these salts are dissolved into the surface water, at least degrading it if not contaminating it. These salt deposits are deposited in even thicker and more extensive layers in a playa lake. These low, flat lakes form in the spring from runoff but quickly dry out for most of the year. The water in these lakes is generally not potable and a pollutant to any other water sources with which it might have contact.

Deserts are extremely fragile environments and probably least able to absorb pollution even though

they may get the most. The food and water budget is extremely tight for the fragile ecology in the area. Seeds sit dormant most of the year waiting for the rare rainstorm to germinate and go through a complete life cycle before they dry out and die in the unrelenting sun. Herbivorous animals such as jack rabbits depend on the plants, and their population is tightly controlled by the availability of these plants. In turn, the predator population is controlled by the number of herbivores. The lower the availability of water, the more tightly the ecosystem will be constrained. Plants such as cacti grow extremely slowly and are very sensitive to changes in the environment.



Block diagrams showing the six dune types possible in deserts

Human recreational activities such as driving motorcycles and four-wheelers through the desert, a practice that is especially popular in western states such as California, can do irreparable damage to many of these ecosystems.

On the larger scale, because it has few if any people in it, the desert has been chosen by the federal government as the best place to carry out some of the most dangerous operations to people and the environment, namely, military testing and radioactive waste disposal. The Nevada Test Site is the location where nearly 1,000 nuclear tests have been carried out over the past 55 years. At first, tests were at the surface or even in air, but later all were conducted underground. Even underground, the amount of radioactive fallout from these tests is tremendous and now coats the area for tens of miles around the site. The detonation sites themselves are completely destroyed and will remain so for centuries. The government has also tested numerous types of conventional weapons in the desert and still does on a regular basis. Storage of dangerous weapons such as nerve gas and biological weapons is considered to be safer in the desert because, in the event of an accident, there will be less impact on society.

In addition to the direct pollutants from defense testing of conventional weapons such as lead from bullets and phosphorus from incendiary devices, there is pollution from regular release of fuel, solvents, particulate, polycyclic aromatic hydrocarbons (PAHs), and other combustion products from bases and normal operations. This waste can be more damaging to the environment in a desert than in temperate areas because the ratio of waste to groundwater is much higher and, as such, is more bioavailable.

The final type of waste that is specifically disposed of in deserts is radioactive waste. Both the Waste Isolation Pilot Plant (WIPP) and the Yucca Mountains high-level radioactive waste repository are located in the deserts of the southwestern United States. Great precautions have been taken in both cases to prevent leakage of radioactive waste into the environmental systems. They are as safe as possible under the circumstances, but any small leak could be devastating to the areas. The construction of each of these facilities has greatly disrupted the local environment of the areas. It has included disruption of the soil and introduction of pollutants common to construction sites such as solvents, fuel, and various air pollutants.

See also LEAD; PAH; PARTICULATE; PHOSPHORUS; RADIOACTIVE WASTE; WASTE ISOLATION PILOT PLANT; YUCCA MOUNTAIN WASTE REPOSITORY.

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**diazinon** The pesticide diazinon was found in only 25 of the first 1,678 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where it was analyzed, and yet it was rated number 56 of the worst 275 substances on the 2007 CERCLA Priority List of Hazardous Substances. The reason that it is considered so dangerous is that it is one of the top insecticides for incidents of poisoning of humans and wildlife. Diazinon was first restricted in 1988 (restricted use pesticide [RUP]) when the EPA prohibited its use on golf courses and sod farms, among other areas. The restriction was partly removed in 1996, but recently diazinon was more stringently restricted when on December 31, 2004, it was banned from all outdoor, nonagricultural products. Diazinon is also known as Alfatox, Basudin, AG 500, Bazinon, Dazzel, Desapon, Dianon, Diazide, Drexel, Gardentox, Kayazinon, Kayazol, Knoxout, Nucidol, Sarolex, and Spectracide, among about 500 registered products.

## PROPERTIES, USE, AND PRODUCTION

Diazinon is a nonsystemic organophosphate insecticide, acaricide, and nematicide that does not occur naturally. Pure diazinon is a clear, colorless, odorless liquid, but it is most commonly used in agriculture and extermination as a pale to dark brown liquid of 85–90 percent purity. Residential use is most commonly with 5 percent preparations. Other forms include dust, wettable powders, granules, emulsifiable solutions, seed dressings, and agricultural concentrates. It has been used to control cockroaches,

silverfish, ants, fleas, ticks, scavenger wasps, aphids, spiders, worms, grubs, nematodes, and mealybugs and to protect fruits, vegetables, coffee, tea, cotton, tobacco, rice, corn, alfalfa, potatoes, ornamental plants, rangelands and pastures, sod farms, golf courses, and animals, both pets and livestock. It was developed in 1952 for agricultural and residential applications. Approximately 13 million pounds (5.9 million kg) of diazinon was applied annually between 1987 and 1997. About 20 percent of the usage was on agricultural crops and livestock, about 39 percent for turf and homeowner control of insects, 19 percent for lawn care operators, and 11 percent for exterminators. As part of the restrictions, production of diazinon was reduced by 25 percent in 2002 and 50 percent in 2003 with corresponding cancellation of 20 uses on food crops.

### ENVIRONMENTAL RELEASE AND FATE

As with most pesticides, virtually all of the diazinon produced has been released to the natural environment as a nonpoint source pollutant. Only that which is improperly disposed of or spilled during manufacture, transport, or storage is a point source pollutant. Diazinon is primarily released to the soil and enters surface water through runoff and the atmosphere through evaporation. Diazinon has a removal half-life in soil of 14–80 days (average 40) but can persist for six months under low-temperature, low-moisture conditions. It is removed by hydrolysis reactions and microbial activity. Diazinon can slowly leach through soil and contaminate groundwater. It was identified in water from 54 wells in California alone. Diazinon has been most frequently found in surface water that drains residential areas originating in runoff from home and lawn use, rather than in agricultural areas. It has been found in surface waters in 24 states and the District of Columbia and has been the most common pesticide found in surface water nationally. It has also been found in tap water in Canada and Japan. It degrades quickly in most surface waters, with a typical removal half-life of one to six days. In waters with neutral pH, however, one study found it to persist with a removal half-life of 185 days. Diazinon can also enter the atmosphere from spraying and evaporation at rates of up to 25 percent of that applied. A 1995 U.S. Geological Survey study found that air and rain from many urban and agricultural areas had detectable levels of multiple pesticides. Diazinon was found in the most areas with the highest concentration of any of them. It was also one of five pesticides that were found to be capable of concentrating in fog droplets. The states with the high-

est environmental release of diazinon are California, Texas, and Florida.

Diazinon is very toxic to birds (the main reason for the RUP status), mammals, bees, freshwater fish, and aquatic invertebrates. From 1994 to 1998, diazinon had the highest number of bird kill incidents resulting from pesticide exposure and the second highest number of all time. There were reports involving 23 species in at least 18 states. Diazinon had the most ecological incidents for all organophosphates at 21 percent of the total. About 11 percent of the incidents involved aquatic organisms. Diazinon is absorbed through plant roots and translocated throughout the plant. The removal half-life for plants is two to 14 days.

### HEALTH EFFECTS FROM EXPOSURE

Diazinon has moderate toxicity for both animals and humans, rated as a class II pesticide (I is strongest; IV is weakest) by both the EPA and World Health Organization, at full strength. It is a strong blood plasma and brain cholinesterase inhibitor by inhalation, ingestion, or dermal exposure. Acetylcholinesterase is an essential enzyme for normal nerve transmission. Effects of acute exposure to diazinon include headache, muscle weakness and tremors, sweating, blurred vision, pinpoint pupils, slurred speech, labored breathing, slowed reflexes, lapses in memory, slowed heartbeat, salivation, nasal discharge, nausea, vomiting, diarrhea, and abdominal cramps. High doses can induce periodic or continuous convulsions and even cause coma and death. Long-term chronic exposure can cause depression, anxiety, irritability, confusion, muscle twitching, and decrease in body weight, and large doses can damage the pancreas. Diazinon exposure can cause skeletal and spinal deformities in developing bird fetuses and increase the number of stillbirths and neonatal deaths in some mammals. Diazinon is generally not regarded as carcinogenic, even after extensive testing. The only suggestion of a possible cancer link was an epidemiological study that found an increase in non-Hodgkin's lymphoma in farmers in the Midwest, but it is difficult to establish diazinon as the definite cause.

### REGULATIONS ON HUMAN EXPOSURE

To address the numerous adverse health effects from exposure, several federal agencies have established regulations on diazinon. The EPA has established an adult lifetime health advisory for diazinon of six parts per million (ppm) and a one- to 10-day health advisory maximum of 20 ppm in drinking

water. The National Institute of Occupational Safety and Health (NIOSH) limits the workplace to 0.01 milligram of diazinon per cubic meter of air for a 10-hour-workday, 40-hour workweek. Other regulations are under consideration.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; WATER POLLUTION.

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**3,3'-dichlorobenzidine** Dichlorobenzidine was used extensively in the synthesis of certain types of dyes for several decades, especially in the 1960s and 1970s, but that application ended abruptly in 1986 with health concerns and the development of superior substitutes. These health concerns primarily center on its potential as a human carcinogen, and, as a result, it is listed as one of only 13 chemicals that have special designation by both the Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH). Dichlorobenzidine is also available as 3,3'-dichlorobenzidine dihydrochloride and 3,3'-dichlorobenzidine salts, among others. Dichlorobenzidine was found in only 32 of the first 1,467 U.S. Environmental Protection Agency (EPA)-designated Superfund sites (National Priorities List) where it was analyzed, but it was rated a very high number,

40 of the 275, substances on the 2007 CERCLA Priority List of Hazardous Substances. It is because dichlorobenzidine is considered to be so carcinogenic by so many federal agencies that it garners such a position in spite of its scarcity.

#### PROPERTIES, USE, AND PRODUCTION

Dichlorobenzidine is a synthetically produced volatile organic compound that is in the category of chlorinated hydrocarbons and does not occur in nature. In pure form, it is a gray to purple solid with a mild odor, but it is commonly used as dichlorobenzidine salt, which is a white crystalline (needles) solid with a faint odor. Dichlorobenzidine was primarily used as a pigment for at least seven shades of yellow as well as some red and orange printing ink, and textiles, paper, paint, plastic, and related items. It also was used in the production of rubber and plastics (curing agent) and as a chemical intermediate in protective clothing manufacture. Dichlorobenzidine was first commercially produced in the United States in 1938. By 1971, domestic production of dichlorobenzidine reached 3.5 million pounds (1.6 million kg) and 5 million pounds (2.3 million kg) in 1972, both of which are not very high. Domestic production never exceeded 10 million pounds (4.5 million kg). As domestic production tailed off in the mid-1980s, imports rose from 208,000 pounds (94,545 kg) in 1979 to 8.7 million pounds (4 million kg) in 2000.

#### ENVIRONMENTAL RELEASE AND FATE

Dichlorobenzidine is most commonly released to the environment as a point source pollutant from a manufacturing, transport, or storage facility as a spill or as a leak from a hazardous waste repository. If it is released to air, the removal half-life is estimated to be 9.7 hours through photolysis (sunlight), although under certain conditions it is said to persist up to 60 days. If dichlorobenzidine is released to water, it will break down very quickly if exposed to sunlight, with a removal half-life of 90 seconds. At deeper levels of lakes and ponds, it tends to bind tightly to particles and settles into the sediments. Removal in these areas is very slow because breakdown by microbial activity is weak. In soil, dichlorobenzidine is very persistent, remaining for several months before it is degraded. Dichlorobenzidine is strongly bioconcentrated by certain aquatic organisms. Bacteria can contain dichlorobenzidine levels 200 to >240 times ambient conditions, but bluegill sunfish can have 1,670 to >2,000 times ambient levels. Predators, including humans, who eat these fish can ingest a



significant dose of dichlorobenzidine. Fortunately, because dichlorobenzidine binds strongly to sediment, bioavailability tends to be low.

According to the EPA Toxic Release Inventory, a mere four pounds (1.9 kg) was released to the environment by industry in 2005. It is reported that 41,861 pounds (19,028 kg) was released in 1998, but 41,600 pounds (18,909 kg) of this was simply transferred off-site for disposal, leaving 261 pounds (119 kg) released directly to the environment. In contrast, some 210,798 pounds (95,817 kg) of dichlorobenzidine was reported released to the environment in 1988, though again, most was simply transferred to an off-site facility.

### HEALTH EFFECTS FROM EXPOSURE

It is the health effects resulting from exposure to dichlorobenzidine that curtailed and, in some cases, eliminated its use. Acute exposure to dichlorobenzidine produces several symptoms related to contact toxicity and central nervous system depression. These symptoms include headache, dizziness, stomachache, sensitized skin, dermatitis, caustic burns, sore throat, upper respiratory tract infection, frequent urination, and blood in the urine. Long-term chronic exposure produces enhanced effects of short-term exposure as well as mild liver damage. When pregnant animals were exposed to dichlorobenzidine, offspring were more likely to have underdeveloped kidneys and develop tumors of the kidneys.

The EPA classified dichlorobenzidine as group B2, probable human carcinogen, and the International Agency for Research on Cancer (IARC) lists it in group 2B, reasonably anticipated to be a human carcinogen. Virtually all evidence for dichlorobenzidine to be listed as a carcinogen is from experiments on laboratory animals, so its danger to humans may not be as great as reported. It was found to produce an increase in cancers of the urinary bladder, kidneys, liver, skin, mammary glands, and Zymbal gland, as well as leukemia. Laboratory studies also show dichlorobenzidine to be mutagenic, resulting in sister chromatid exchange, unscheduled deoxyribonucleic acid (DNA) synthesis, and chromosomal aberrations in several types of cells.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies have imposed restrictions on public and worker exposure to dichlorobenzidine as the result of the severe health effects. The EPA requires the reporting of any spill of dichlorobenzidine of one pound (0.45 kg) or more to the National Response Center. OSHA and NIOSH list dichlorobenzidine as one of 13 potential occupational carcinogens that

require full respiration gear. Under these guidelines, there is to be minimal to no exposure (“de minimis”) of workers to dichlorobenzidine at any time. The NIOSH 1972–74 National Occupational Hazard Survey estimated that 1,100 workers were exposed to dichlorobenzidine in the workplace.

*See also* ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; VOLATILE ORGANIC COMPOUND.

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**dioxin** Dioxin is the common name for a family of organic compounds that are halogenated, the most common of which are the general compounds CDD or PCDD (polychlorinated dibenzodioxin or dioxin) and the related compounds CDF or PCDF (polychlorinated dibenzofuran or furan), the most toxic of which is called TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin). Dioxin gained its fame as a toxin and environmental pollutant through TCDD because it is the active ingredient in Agent Orange and the most notorious pollutant in Love Canal, New York, among other profoundly polluted sites. CDDs and CDFs form a group of 210 congener com-

pounds (135 CDFs and 75 CDDs), but only 17 of them have chlorine in the proper position to be toxic. There is a rating system called the toxicity equivalence factor (TEF) that is used to rate the toxicity of mixtures of these compounds, which ranges from 0 to 1, where 1 is for pure TCDD. The TEF is used to determine toxic equivalency (TEQ) for exposure studies. Dioxin is the subject of a heated controversy between the U.S. Environmental Protection Agency (EPA) and scientific/health organizations who seek to ban it and the chlorinated solvent industry who rely on it. As a result, dioxin has remained in use for many decades past when it was found to be dangerous. It is a testament to the persistence of the chlorinated solvent industry that they have kept dioxin available when far less dangerous compounds have been banned in a much shorter time.

The most recent case of dioxin in the news occurred when the 2004 Ukrainian presidential candidate Viktor Yushchenko went from a handsome, healthy individual to a disfigured, emaciated dying man over a period of several months while on television on a daily basis. For a long time, poisoning was suspected but could not be proven. It was the constant media coverage of the situation that may have saved Yushchenko's life. It is reported that a toxicologist was watching Yushchenko on television and recognized the symptoms of chloracne. The physician who treated Yushchenko claims that it is the second largest dose of dioxin ever administered to a human.

There are several types of dioxin congeners listed on the 275 pollutants of the 2007 CERCLA Priority List of Hazardous Substances. For example, hexachlorodibenzo-p-dioxin and heptachlorodibenzo-p-dioxin are ranked 153 and 154, respectively. The most dangerous congener, tetrachlorodibenzo-p-dioxin, however, is ranked number 73. Dioxins of all types have been found in at least 126 of the first 1,467 EPA-designated Superfund sites (National Priorities List) where they were tested.

### PRODUCTION AND USE

The history of dioxin began around 1900, when Dow Chemical in Midland, Michigan, began producing free chlorine. Over the next several decades, they would use this chlorine to develop chlorinated hydrocarbons, the production of which blossomed during the 1930s and 1940s. These products would be used to develop modern pesticides and solvents and to provide the basis for the plastics industry. Dioxin is produced both by manufacture of these products and by burning them and as such began appearing in the natural environment as early as the beginning of the 20th century. It was not until the



President Viktor Yushchenko of Ukraine on July 4, 2004 (left), and five months later on December 10, 2004 (right), with face disfigured by reported dioxin poisoning (AP Images)

1940s that large quantities of dioxin began appearing in the environment when it began to be produced on purpose, and it peaked in the 1960s during Agent Orange production and use.

### ENVIRONMENTAL RELEASE AND FATE

The current primary sources of environmental dioxin are coal-fired utility plants, metal smelters, transportation sources and especially diesel trucks, waste incineration plants and other disposal burning, polyvinyl chloride (PVC) and other plastic production, paper mills, treatment and use of sewage sludge, and other industries that use chlorine in processing. Small amounts of dioxin are also released from home furnaces and even from cigarettes, where both the tobacco and the white, chlorine-bleached paper are contributors. Dioxin is primarily discharged into the environment as vapor or particulate in air and is then deposited as fallout or precipitation wash-out. As a result, concentrations are higher near the source, but dioxin can travel long distances as vapor, and, as a result, it has been found in lakes in even remote areas. It settles onto water, sediments, soil, and plants by this mechanism. Dioxin can enter the water system directly through discharge from paper and pulp mills and other industry. It can also enter the natural environment from leakage of old stored material, whether buried or in warehouses.

Once it is in the natural environment, a very small part of the dioxin may evaporate or break down from exposure to sunlight and atmospheric chemicals. In surface waters, dioxin tends to bind to particles and settle into the sediments at the bottom. Dioxin binds strongly to the organic component of soils and is generally immobile. The only way it can move into the groundwater system, in most cases,

is if it is dissolved by another chemical and transported. This process is not uncommon in waste sites, where multiple pollutants are present, but otherwise, it is rare. The problem occurs once the dioxin is in the environment. Dioxin tends to adhere to the surface of microscopic organisms, which are then eaten by larger organisms, thus transferring it up the food chain in aquatic and interacting systems (primarily birds). The persistence of dioxin relative to other chemical compounds causes it to biomagnify with each step, reaching dangerous concentrations at the top of the food chain. Terrestrial plants take up only small amounts of dioxin through their roots, but air pollution fallout can coat their leaves and stalks. Grazing animals eat plants coated with dioxin, which enters their bodies and, in turn, those of their predators. Humans, at the top of these chains, are even more susceptible to dioxin exposure.

The EPA estimates that more than 96 percent of human exposure to dioxin is through diet, with 93 percent from meat and dairy products alone. In a typical American diet, the primary source is the ingestion of beef, followed by consumption of dairy, milk, chicken, pork, fish, and eggs, in decreasing order. In terms of contents, butter and freshwater fish have at least twice the concentration of any other sources besides human breast milk, which is also high. The reason that freshwater fish have high concentrations is that those in the study were farm raised and fed a diet of meat, which is high in dioxin. In these other foods, dioxin tends to be stored in fat, so higher fat content typically translates to higher dioxin exposure. A vegan diet is recommended to prevent exposure to dioxins.

### HEALTH EFFECTS FROM EXPOSURE

There have been extensive studies of the effects of dioxin exposure on animals. These studies indicate numerous adverse health effects including skin disease; reproductive damage, such as decreased fertility, decreased sex hormones, reduced sperm levels, and increased miscarriages and birth defects; immunological damage; endocrine system damage; and developmental damage. Rats and mice developed liver, thyroid, and other types of cancer even when exposed to small amounts of dioxin in food for extended periods. It is definitely carcinogenic to some animals. Monkeys also developed behavioral problems and learning disorders when exposed to low concentrations of dioxin.

There are numerous adverse health effects in humans from exposure to dioxin. The most obvious of the effects is chloracne, a severe skin disease that most commonly occurs on the face and upper body.

In severe cases, it can persist for years and be quite disfiguring. Other effects on the skin can be severe skin rashes and excess body hair growth. Dioxin has also been shown to cause liver damage including inability to metabolize hemoglobin, lipids, proteins, and sugar properly. These effects are mostly reversible, but full recovery can take years. Some studies indicate an increased risk of diabetes and abnormal glucose tolerance indicating damage to the pancreas. Dioxin has also been shown to cause learning disabilities, delay motor skills development, and lower IQ scores in exposed children. Moderate to severe immunological damage has also been found in some studies. These problems are commonly passed from generation to generation because dioxin is so persistent that it takes seven years to remove half of a dose of dioxin from the human body.

### REGULATIONS ON HUMAN EXPOSURE

The World Health Organization's International Agency for Research on Cancer and the U.S. Department of Health and Human Services National Toxicology Program both consider dioxin to be a potent human carcinogen. In a preliminary report, the EPA found that the lifetime cancer risk is increased 1,000 times though exposure to dioxin. Normally, all of these documented and suspected problems would be enough to have a substance banned from use. The chlorinated solvent industry, however, has sponsored a large amount of research that found conflicting and contradictory results to those of the previous studies that issued dire warnings. They have also lobbied elected representatives to protect dioxin and related compounds. As a result of the confusion, there are no laws governing exposure to dioxin, just recommendations and advisories. There are 66 health advisories issued by 21 states that restrict the consumption of dioxin-contaminated fish and game. The EPA has recommended limits on dioxin in drinking water of one nanogram per liter of water per day of single exposure and not more than 0.01 nanogram per liter of water in long-term exposure for children and not more than 0.04 nanogram per liter of water for adults.

*See also* BIOACCUMULATION AND BIOMAGNIFICATION; ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**disulfoton** A pollutant that is not common in hazardous landfills nevertheless can be a significant environmental threat. The pesticide disulfoton was found in only seven of the first 1,430 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where it was analyzed, and yet it was rated number 38 of the 275 pollutants on the 2007 CERCLA Priority List of Hazardous Substances. The reason for its high ranking is that disulfoton is a widely used and effective pesticide. Pesticides are designed to control pests by poisoning them, but it is impossible to produce toxic substances that are selective enough not to have significant adverse health effects on other organisms, including humans. Disulfoton is highly toxic to many organisms and exposure is high. Disulfoton is also known as Bay 19639, Di-Syston, Dimaz, Disipton, Disulfoton-diethyl, Disyston, Disystox, Dithiodemeton, Dithiosystox, Ekatin TD, ENT-23427, Ethylthiodemeton, Ethylthiometon, Frumin AL, Glebofos, M 74, phosphorodithioic acid, Solvigram, Solivirex, and Thiodemeton, among others.

### PROPERTIES, USES, AND PRODUCTION

Disulfoton is a chemically synthesized organophosphate insecticide/acaricide and nematicide. It is a colorless oil in pure form but available as an emulsifiable concentrate, liquid, granules, pellets, and dust. It is used in both agricultural and residential applications and in control of mosquitoes in

swamps. Agricultural uses of disulfoton are in field crops such as corn, sorghum, alfalfa, cotton, wheat, soybeans, and oats as well as fruits and vegetables such as asparagus, broccoli, brussels sprouts, cabbage, cauliflower, lima beans, string beans, potatoes, peanuts, peas, peppers, and tomatoes. It is also used on nonfood crops such as tobacco, ornamental plants and shrubs, potted plants, Christmas trees, and other nonfruit trees. It is effective against sucking insects including aphids, grasshoppers, leafhoppers, thrips, rootworm, scale, psyllids, leaf miners, spider mites, white flies, mealybugs, wireworm, webworm, and others. Typical annual application of disulfoton in the United States is approximately 1.2 million pounds (545,454 kg). The primary use is on cotton (420,000 pounds, or 190,909 kg), wheat (220,000 pounds, or 100,000 kg), potatoes (180,000 pounds, or 81,818 kg), Christmas trees (80,000 pounds, or 36,364 kg), and tobacco (60,000 pounds, or 27,273 kg).

### ENVIRONMENTAL RELEASE AND FATE

Disulfoton is primarily applied to soils in large agricultural areas and is, therefore, largely a nonpoint source pollutant, although it can also be a point source pollutant if spilled during manufacture, storage, or transport. Disulfoton binds moderately to soil and, as such, in most cases, has a low to moderate persistence. It may break down quickly to its metabolites, sulfoxide and sulfone, by temperature-dependent chemical reactions and microbial activity. The metabolites are also insecticidally active and environmental health threats, and they can persist for long periods. Higher organic matter, high alkalinity, and higher temperatures result in rapid degradation of disulfoton. In paddy soils, the disulfoton breaks down quickly, but the metabolites persist for a long time. The variable soil conditions result in a variable-removal half-life (removal of half of the mass) of 3.5–290 days, which means that it can persist for a long time. Disulfoton typically does not leach deep into the soil depending upon temperature and chemistry, and, as a result, it is uncommon in groundwater. Agricultural runoff, however, can deliver a significant amount of disulfoton to surface water. Chemical reactions and microbial activity, however, remove it relatively quickly, with a half-life of about seven days under alkaline conditions and higher temperatures.

Disulfoton has strong adverse ecological effects. It is moderately toxic to birds but highly toxic to bees, fish, and most other marine and aquatic invertebrate organisms. It has a bioconcentration factor of 460 times ambient levels, which is considered moderate.



Disulfoton is actively absorbed by plant roots and distributed throughout the plant, persisting there for six to eight weeks. This property makes exposure for animals and humans much higher.

### HEALTH EFFECTS FROM EXPOSURE

There are many adverse health effects from exposure to disulfoton. Acute exposure with high dosage through inhalation and ingestion primarily affects the central nervous system, lungs, and gastrointestinal tract. The primary reason for the reactions is that it is a strong cholinesterase inhibitor in humans. Symptoms of acute exposure include sweating, headache, fatigue, tearing and blurred vision, salivation, nausea, vomiting, diarrhea, stomach cramps, coughing, loss of coordination, muscle twitching, confusion, convulsions, pulmonary edema, respiratory paralysis, coma, and death if the dose is high enough. Disulfoton is also a powerful irritant to the skin and membranes. It causes skin rashes and burns, and, in the case of eye contact, it can cause severe burns and even permanent damage, primarily nearsightedness. It may take up to three weeks to recover from the nonpermanent effects. Long-term chronic exposure causes immediately noticeable effects of flulike symptoms, loss of appetite, weakness, irritability, delayed reaction times, anxiety, and memory loss. It has also been shown to increase the likelihood of cataracts in humans. Such exposure has also caused damage to the spleen, kidneys, liver, pituitary glands, and brain in laboratory animals and decreased fertility, smaller litter size, as well as incomplete bone and testes development, and damaged livers and kidneys in offspring when pregnant animals were exposed to disulfoton. There is no evidence that disulfoton is a carcinogen.

### REGULATIONS ON HUMAN EXPOSURE

Although disulfoton is not covered under the Safe Drinking Water Act, the EPA has recommendations for exposure for both children and adults. They recommend a maximum of 10 parts per billion (ppb) of disulfoton in drinking water for children for periods up to 10 days. For longer periods, it should not exceed 3 ppb for children or 9 ppb for adults, but over a lifetime, it should not exceed 0.3 ppb, which is a very low concentration. The EPA requires the reporting of any leak or spill of disulfoton of one pound (0.45 kg) to the National Response Center. The National Institute of Occupational Safety and Health (NIOSH) limits the workplace to 0.1 milligram of disulfoton per cubic meter of air for a 10-hour-workday, 40-hour workweek. The Occupational Safety and Health Administration (OSHA)

has the same limit over an eight-hour-workday, 40-hour workweek.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**Doe Run smelter Herculanum, Missouri 2001 Air Pollution** Lead is a very useful industrial mineral. It is easy to shape, has a low melting point, is resistant to corrosion, has unusual electrical properties, is very dense, and is relatively abundant and, therefore, inexpensive. These properties make it the ideal material for balancing and other weights, ballistic projectiles or bullets, car batteries, radioactive shielding, some paints; as a component for some glass and a chemical additive in some industrial processes; and in hundreds of other uses upon which a modern standard of living depends. In the past, it was even more commonly used, when it was an additive to all gasoline, oil paints, and solder for plumbing and electronics. These uses were discontinued in the 1970s and 1980s for health reasons.

Galena, or lead sulfide (PbS), is a soft, heavy mineral recognized by its distinctive cubic shape (cleavage), dark gray color, and ability to mark paper and other objects (streak). In the United States and many other countries, it is the principal source or ore mineral of lead. In the United States, lead is

most extensively mined in Missouri, Kansas, and Oklahoma. Galena in this region is found in irregular veins and pockets of limestone and other sedimentary rocks, thought to have been deposited by warm, mineral-bearing groundwater forced out of the Ouachita Mountains as they were being tectonically compressed and uplifted more than 350 million years ago.

### BACKGROUND

Missouri received more than its fair share of this galena-rich groundwater. To the east, south, and west of the Saint Francois Mountains, about 40 miles (64.4 km) southwest of Saint Louis, French explorers in the 1700s found thick deposits of galena literally lying on the surface of the ground. It was eroded out of the soft sedimentary rock in which the mineral had crystallized. By the mid-1800s, the easily exploited surface deposits had been removed and underground mining began. Around 1955, a new set of lead deposits was found in a north-south trending zone west of the Saint Francois Mountains, called the Viburnum Trend, named after a small town in the area and sometimes referred to as the New Lead Belt. More than 40 miles (64.4 km) long and up to a half-mile wide (0.8 km), but only 1,000 feet (304.8 m) below the surface, the Viburnum Trend is certainly the United States' and perhaps the world's most important source of galena.

Numerous companies, both small and large, have mined galena in Missouri over the last 200 years. The historic operations of Renault Lead, Palmer Lead, R. Smith & Company, and the St. Joseph Lead Company, the first to develop mines in the Viburnum Trend, have been consolidated into a few large corporations. One of the largest of these is the Doe Run Corporation. Saint Louis-based Doe Run is the third largest lead mining and smelting company in the world. The company also recycles, on an annual basis, more than 150,000 tons (136,078 metric tons) of lead from waste batteries and telephone cables. Doe Run owns facilities in Missouri, Washington, Arizona, and Peru and employs more than 4,000 people. Doe Run operates two fairly modern and efficient lead smelters in Missouri, one in Glover and one in Herculanum. The legacy companies that Doe Run acquired and its own record of spotty environmental compliance have resulted in a lingering and difficult-to-resolve public health crisis.

### CONTAMINATION OF THE SITE

Doe Run's lead smelter in Herculanum, Missouri (current population about 2,800), first began operations in 1892. Currently, the 50-acre (20.2-ha)

facility, located about 25 miles (40.2 km) south of Saint Louis, processes lead ore trucked in from eight Viburnum Belt mines. Present on the Herculanum site are the smelter, a waste slag storage pile, and a sulfuric acid plant, which converts sulfur released during ore smelting into a valuable commercial product. During smelting, some lead is released into the atmosphere. Lead particles also are blown off a pile of waste rock that is 24 acres (9.7 ha) in area and 40–50 feet (12.5–15.2 m) high. In 2005, the Doe Run smelter at Herculanum emitted an estimated 28 tons (25.4 metric tons) of lead to the atmosphere and added more than 750 tons (680.4 metric tons) of lead-contaminated slag and debris to its stockpile on its property.

Although air pollution control devices and changes in operational procedures are helping Doe Run collect and manage these emissions generally in accordance with its Clean Air Act permit, historic operations and periodic upsets have resulted in leads being distributed throughout Herculanum. The geography of Herculanum compounds the problem. Numerous homes abut the smelter's western and northwestern boundaries, within a few hundred yards of the smokestack and slag pile. Most industrial plants have a buffer of unoccupied or commercial property around them, which gives blowing dust or air emissions a chance to settle on the industrial property before entering a residential neighborhood. At Herculanum, there is no buffer strip, and the



Smokestack at Doe Run Company lead smelter near homes in Herculanum, Missouri, 2002 (AP Images)

homes and backyards have been pressed up against the smelter's property line for the past 100 years. They are regularly coated in lead-contaminated dust generated from ore delivery trucks during loading and unloading, storage and disposal of ore and slag, and material processing. Even the long-used access road to the plant contributes to the problem.

A dust sample collected from this access road contained 30 percent (300,000 mg/kg) lead. Missouri health guidelines warn against having direct contact with soil that has a concentration of more than 0.4 percent (400 mg/kg) lead. Subsequent sampling by the Missouri Department of Health and Senior Services (DHSS), U.S. Environmental Protection Agency (EPA), and other government agencies found high levels of lead to be everywhere in Herculanum, including on door and window sills, in schoolyards and backyards, and even in vegetables in local gardens.

### HEALTH CRISIS AT THE SITE

Lead is toxic to humans. It damages the central nervous system, particularly in the young and unborn, and exposure to elevated lead levels can result in anemia, premature birth, decreased mental ability, low birth weight, and reduced growth. Adults also can be affected, and the most common symptoms consist of decreased reaction time and weakness in fingers, ankles, and wrists. Lead also has been shown to cause cancer in lab animals. Current federal guidelines recommend blood lead screening for all children between six months and six years of age and require medical monitoring and treatment for children with blood lead levels of 10 micrograms/deciliter (10 mcg/dL) or more.

Public health surveys conducted in 2001 examined blood lead levels of 935 people living next to and close by the Doe Run smelter. Of the almost 120 children younger than six years of age who were tested, 28 percent had blood lead levels known to cause adverse health effects. Concentrations of lead in their blood ranged from 10 mcg/dL to 31 mcg/dL. Older children, between six and 17 years of age, fared better: Only 13 (8 percent) had blood lead levels above 10 mcg/dL, with the highest reported value 19 mcg/dL. Overall, within one-half mile (0.8 km) of the smelter, 50 percent of the children tested had unsafe blood lead levels.

On the basis of these data, as well as an examination of conditions within the town, the DHSS concluded that the residents of Herculanum have been exposed to lead in the past and that exposure is ongoing and likely to continue into the future. DHSS classified the site as an "urgent public health

threat" and recommended that immediate steps be taken to develop and implement mitigative measures, particularly focused on young children, to reduce exposure to the lead present in the soil and air at Herculanum.

### REMEDIAL ACTIONS

Yielding to pressure from both federal and state regulatory agencies and the local community, Doe Run began to take steps to address the problem. It purchased 26 homes of families within a half-mile (0.8 km) of the plant who had children less than six years old and made purchase offers on another 134 homes in the same area. Doe Run funded a community education program, warning people of the dangers of lead and stressing the importance of consistently practicing good personal hygiene, including frequent hand washing, regularly cleaning outdoor playground equipment, and avoiding dusty areas, as well as encouraging periodic blood level testing for children. The company expanded a program it began in the 1990s to dig up and replace topsoil in backyards that contain elevated concentrations of lead.

As a company, Doe Run continues to struggle with its obligation to address the environmental and public health issues created by its own operations, as well as those it inherited from predecessor companies. Its critics say that Doe Run has been slow to respond and has only reluctantly implemented solutions imposed by regulatory agencies to deal with the crisis in Herculanum. However, the company is walking a monetary tightrope. It needs to balance its fiduciary obligations to its shareholders and employees to remain a profitable and growing business with demands to implement a financially overwhelming set of cleanup obligations immediately. How that dynamic plays out will, in large part, determine the ultimate environmental fate of Herculanum.

*See also* AIR POLLUTION; LEAD; SOIL POLLUTION.

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**Donora Killer Fog Donora, Pennsylvania October 30, 1948 Air Pollution** In his radio broadcast of Saturday, October 30, 1948, the famous commentator and reporter Walter Winchell focused the attention of his nationwide audience on the worst air pollution disaster in America since the 1930s dust bowl. Using his trademark staccato, rapid-fire delivery, Winchell vividly portrayed the pain and suffering that the residents of Donora, Pennsylvania, were experiencing from a freakish “killer fog.” Unlike the dust bowl, however, this disaster resulted from industrial pollution. This event would be one of the predecessors of those in the 1950s that inspired the American environmental movement.

## BACKGROUND

Donora, Pennsylvania, had a population in the 1940s of around 14,000 and was a working class/industrial community about 40 miles (64.5 km) southwest of Pittsburgh. Nestled in a picturesque valley of western Pennsylvania, Donora proudly boasted being the home to two of the largest metalworking mills in the United States, the Donora Zinc Works and American Steel & Wire, both owned by U.S. Steel Corporation. This almost four-mile- (6.4-km-) long industrial complex hugged a horseshoe-shaped bend of the western side of the Monongahela River, adjacent to and upwind of Donora’s downtown and residential area. These plants, employing some 6,500 men and women, turned iron and zinc ores into steel, nails, fencing, wire, and other finished goods.

The small valley that the Monongahela River had carved out of the limestone bedrock had a smooth flat bottom, about one mile (1.6 km) wide, protected by hills that rose almost 500 feet (152.4 m) above the river’s surface. Industry was first attracted to this area because of its proximity to Pennsylvania’s coal mines and the ease with which coal and other raw materials could be delivered, and finished goods shipped, up and down the Monongahela. In the early 1900s, the first steel mill opened, and, by 1916, the glow of blast furnaces, stench of sulfur, and steady parade of river barges would dominate the lives of the townspeople for the next 40 years. The citizens

of Donora were mostly immigrants seeking high-paying jobs in the mills.

The production of the mills was staggering. Donora claimed to be the largest maker of nails in the world. This was postwar America, the peak of the country’s manufacturing prowess, with Donora a major part of that industrial juggernaut. Coal, at volumes up to 40 barge loads per day, was necessary to keep this mighty economic engine running. Coal fired the red-hot, open-hearth furnaces, ovens, and vats where the iron and zinc were melted. Impurities from these processes, mostly sulfur oxides but also zinc, fluoride, and other metals, as well as coal ash and soot, were collected and discharged through a series of 150-foot- (45.7-m-) high smokestacks. Residents would often gather in their backyards in the evening to watch the spectacular sunsets brought on as the waning daylight was reflected off the particulate suspended in the air. In the 1940s, such air pollution control devices as baghouses or scrubbers were unheard of, and most people, not only in Donora, but also in Pittsburgh, Detroit, Cleveland, and other major industrial American cities, were content to trade an occasional foul smell or dead front lawn for a steady paycheck.

## THE AIR POLLUTION EVENT

Donora was no stranger to the ill effects of air pollution. Since the 1920s, the mill owners and operators quietly paid claims for damages to crops and livestock originating from the factories. As early as 1918, the zinc works compensated nearby residents for health care costs related to breathing in the noxious fumes and mists released by the plant. Nothing, however, prepared the town for what began in the early morning hours of October 26, 1948, and continued for the next four days. On the crisp autumn evening of October 25, a blanket of cool, dry air silently settled over the town and created a very effective seal. The sulfur oxides, metals, and particulates being discharged out of the low smokestacks started to build up and began to reach dangerous levels. The cliffs surrounding Donora are 500 feet (152.4 m) high, yet the smokestacks were less than 200 feet (61 m) tall. As the next day began, the effects of this temperature inversion started to be noticed.

The air began to turn yellow and then gray. By Friday, October 29, most of the town was covered with a dark haze that seemed just right for the annual Halloween parade. The next morning, nine elderly residents of Donora were found dead in their homes, asphyxiated as they inhaled a fine mist of sulfuric acid formed when the sulfur oxides mixed with





Donora, Pennsylvania, 1948 (Alfred Eisenstaedt/Time & Life Pictures/Getty Images)

water vapor in the air. The following day, police and fire department officials announced an increase in the death toll to 18. The Saturday afternoon high school football game was played in a dense fog, with the crowd unable to see either the players or the action on the field. By midafternoon, it was unsafe to drive and those brave enough to venture outside could not see their own shoes.

Doctors began to urge those who had respiratory problems to leave town, but as many residents tried to flee, the fog and congested streets made an orderly evacuation impossible. By Sunday, the town's funeral home had run out of caskets. Firefighters were called out to go from house to house to give those struggling to breathe a few quick swallows of oxygen from their air packs before moving on to the next home. Incredibly, the zinc and steel mills kept operating throughout most of the disaster, pumping more and more contaminants into the air. It was not until early Sunday morning that U.S. Steel grudgingly gave the order to shut down the plants. By then, 20 people between the ages of 52 and 85 had died, and the town had opened a makeshift morgue

in the community center. More than 7,000 people, over half the population, were ill with headaches, stomach cramps, and vomiting.

Late Sunday afternoon, the weather finally broke, and a rainstorm slowly washed most of the pollution out of the air. The mills promptly reopened. Another 50 residents died within a month of the disaster, but these fatalities were never officially attributed to the "killer fog." U.S. Steel settled lawsuits without admitting blame by calling the fog an "act of God." For the most seriously injured, settlement amounts ranged from \$1,000 to \$30,000. Concentrations of airborne sulfur dioxide were estimated to have been between 1,500 and 5,500 mcg/m<sup>3</sup>. Today's regulations prohibit the discharge of sulfur dioxide at concentrations greater than 80 mcg/m<sup>3</sup>.

### THE AFTERMATH

A series of investigations began within a few months of the disaster. The U.S. Public Health Service, U.S. Steelworkers Union, and Pennsylvania Department of Health all collected data, took extensive health

histories, and tried in a scientific manner to determine what happened. Some of these and other studies were criticized as being incomplete, inaccurate, or not rigorously performed. This, however, was the first time an organized effort was made by governmental agencies in the United States to document the effects of air pollution on public health.

It was Donora that placed the issue of clean air on the national agenda. As a result of the disaster, in 1955, Pennsylvania passed the first air pollution control law in the United States in direct response to the catastrophe at Donora. The Donora smog, as well as other air pollution events, led to congressional hearings on air quality in the United States and, eventually, the Clean Air Act of 1963.

The Donora mills closed in the late 1960s, unable to compete with cheaper overseas labor and energy and more modern plants. Donora's population decreased to less than half, as people left town in search of better opportunities. Today, a beautiful bronze marker, erected in what was the center of the now-demolished Donora Zinc Works, tries to honor those who died in the 1948 disaster. Their real legacy, however, is some of the strictest air pollution control laws in the world.

*See also* AIR POLLUTION; DUST BOWL; PARTICULATE; SULFUR OXIDE CONTROL TECHNOLOGIES; ZINC.

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**Dover Air Force Base Dover, Delaware 1983–present** *Water Pollution* In 1939, the City of Dover, Delaware, made a \$35,000 investment that

would grow into Delaware's third largest industry. With some prodding by the Federal Civilian Aviation Administration (later to become the Federal Aviation Administration, or FAA), Dover purchased 587 acres (237.6 ha) of scrub forest and farmland about three miles (4.8 km) southeast of downtown and slowly began developing Dover Municipal Airport. By March 1941, the "airport" consisted of three hard-surface runways and a foundation for a hangar. Nine months later, the Army Air Corps leased the barely completed facility, and bomber squadrons were using it as they flew antisubmarine patrols along the East Coast during the early days of World War II. Today, some 3,800 active-duty military and civilian employees live and work on the 4,000-acre (1,619-ha) Dover Air Force Base (Dover AFB), supporting such missions as the evacuation of Americans from Iran in 1979; the airlifting of troops, equipment, and humanitarian aid to Somalia in 1992; and the massive Desert Shield/Desert Storm airlifts in 1990. Dover AFB contributes more than \$470 million to Delaware's economy, and its capital assets and aircraft-related equipment add \$5.8 billion to the value of America's defense resources.

#### CONTAMINATION AND INVESTIGATIONS

During its operational life as a very active and fairly compact military installation, materials used in the operation, repair, and maintenance of aircraft and base facilities were spilled or discharged onto the ground. Dover AFB managed these wastes in accordance with general industry practices at the time, which did not place a premium on the environmental consequences of how these types of materials were handled. The main types of wastes generated included spent industrial solvents and petroleum hydrocarbon-related compounds (e.g., waste oil and fuels), but pesticides, plating wastes, and paints also were generated. In 1989, Dover AFB was placed on the National Priorities List (NPL) as a Superfund site so that the U.S. Air Force (USAF) could more effectively investigate and remediate its environmental issues within the framework of this national program and ensure close cooperation with the U.S. Environmental Protection Agency (EPA) and the Delaware Department of Natural Resources and Environmental Control (DNREC). Subsequent to NPL listing, USAF entered into a Federal Facility Agreement (FFA) with EPA Region III and the DNREC to establish an overall approach for completing remedial activities at the base.

One of the first environmental investigations initiated at the base began in 1983 and was related to assessing potential groundwater impacts of an



on-base landfill that had been used for the disposal of construction and demolition debris. Since then, some 20 operable units, which encompass almost 60 different locations, have been identified as having the potential to contain hazardous wastes or hazardous waste constituents. These sites have been grouped into four major waste management units, the East Management Unit, the North Management Unit, the West Management Unit, and the South Management Unit. Nine areas of groundwater contamination (called Areas 1 through 9) also have been identified, and they have been added to the waste management units. A brief summary of each waste management unit is provided in the following:

#### **North Management Unit**

This area includes runways, taxiways, access roads, and open fields, with its main feature a drainage ditch that received unprocessed industrial wastes in the 1950s and treated industrial wastewater in the 1960s. Since 1969, the ditch has been used only for the drainage of storm-water runoff away from the North and West Management Units.

#### **East Management Unit**

This unit is made up of an ammunition storage facility and a hazardous cargo storage building. Overall it contains nine hazardous waste disposal sites and

also includes Area 1, a groundwater plume associated with previous waste disposal activities. The major constituents of this plume are chlorinated solvents and their breakdown products.

#### **South Management Unit**

This unit comprises 10 sites, which include landfills, a fire training area, fuel releases, oil/water separators, underground storage tanks, and a hazardous waste storage area. Three different plumes of contaminated groundwater are associated with the South Management Unit, two containing chlorinated solvents and the third made up of vinyl chloride and benzene.

#### **West Management Unit**

This unit is the largest and contains 40 sites and five areas of contaminated groundwater. Aircraft parking aprons, base housing, shops, a golf course, and administrative offices are within this management unit. Contaminant sources vary; they include landfills, a fire training area, miscellaneous fuel releases, oil/water separators, a pesticide storage and handling facility, underground storage tanks, several former industrial waste basins or ponds, an industrial waste collection drain system, and the former wastewater treatment plant. Contaminants found in the groundwater plumes are related to either petroleum hydrocarbons or chlorinated solvents.



**Air Force C-17 lands at Dover Air Force Base, Dover, Delaware** (Alex Wong/Newsweek/Getty Images)

## REMEDIATION OF THE SITE

Remedial actions at Dover AFB have been focused on addressing the control and spread of contamination from each of the management units. Cleanup activities have removed grossly contaminated soil from landfills, excavated buried drums from a fire training area, and decommissioned a concrete basin along with associated sludge and soil that had been used as part of the base's wastewater treatment operations. The majority of the oil/water separator systems at the base have been removed or replaced and upgraded. Groundwater plumes have been defined and are being monitored so that off-base users are not being placed at risk.

Dover AFB has been diligent (with some periodic prodding by the regulatory agencies) in investigating and assessing potential off-base impacts related to its former waste management practices. In 1984, volatile organic compounds (VOCs) were detected in groundwater from supply wells at a trailer park and other off-base, private properties southwest of Dover AFB. Even though contaminants were below levels at which adverse health effects were expected to occur, and it is likely that contaminants released from a local gas station and dry cleaner may have contributed to the levels of reported VOCs, both the trailer park and several other residences and businesses were connected to the municipal water system by Dover AFB.

Three ball fields that had been part of a landfill for the base were investigated to determine whether they pose a threat to the children and adults who use them. This landfill was used for disposal of construction debris and household refuse in the 1950s and 1960s. An investigation of soil gases being emitted through the cover of the landfill found that levels were so low that no further action was warranted and that the use of the landfill for recreational purposes did not entail a significant risk to children or adults.

More than half of the individual hazardous waste disposal sites have either been recommended for no further action or remediated to cleanup standards. Impacted groundwater is being addressed either through monitored natural attenuation, separate-phase recovery, or accelerated anaerobic bioremediation. The EPA has approved cleanup plans for each of the 20 operable units, and they are in various stages of remedial design, construction, or implementation.

For example, Building 719 is tucked away in a corner of Dover AFB. Inside this building, jet engines were cleaned, repaired, upgraded, and tested. Essential to these activities was the liberal use of chlorinated solvents and degreasers, primarily trichloroethylene (TCE), trichloroethane (TCA),

and dichloroethane (DCE). These solvents, however, were not always handled carefully, and soil and groundwater beneath the building became contaminated, probably as a result of a leaky underground storage tank and a faulty industrial sewer system. In 1997, the Bioremediation Consortium of EPA's Remediation Technology Development Forum (RTDF) selected Building 719 as the first test site for the use of cometabolic bioventing. The RTDF was formed in the early 1990s to encourage joint public-private sector development of innovative remedial technologies.

During the RTDF's initial study, about half of the 84 soil samples collected within a 500-square-foot (46.5-m<sup>2</sup>) test plot found that the contaminated area around Building 719 contained concentrations of TCE, TCA, and DCE greater than 0.25 mg/kg. Contamination was present above the water table and within 10 feet (3 m) of the surface. The Delaware soil standard for the protection of groundwater limits TCE and DCE concentrations in soil to 0.028 mg/kg and 0.029 mg/kg, respectively.

When petroleum hydrocarbons and chlorinated solvents are present in the subsurface, a natural degradation process called cometabolism or cooxidation can occur. Cometabolism is the simultaneous utilization of two compounds, in which the degradation of the second compound (the chlorinated solvent) depends on the presence of the first compound (the petroleum hydrocarbon). During aerobic processes, bacteria generate monooxygenase (MO) and dioxygenase (DO) enzymes that serve to metabolize the petroleum hydrocarbon. These enzymes break up the petroleum hydrocarbon so that the bacteria can use it as a food source (a substrate, or electron acceptor).

Chlorinated solvents have chemical structures similar to those of petroleum hydrocarbons, and the MO and DO enzymes have been found to catalyze the chlorinated solvents that are mixed in with the petroleum hydrocarbons. This process is called a fortuitous reaction, because the bacteria cannot use the chlorinated solvents' transformation products as a substrate (food source) and gain no nutritional benefit from the breakdown of these compounds. The reason that the bacterial enzymes degrade the chlorinated solvents is still somewhat unclear. The cometabolic or cooxidation reactions are thought to inhibit the eventual formation of harmful chemicals, or the bacteria may need some type of secondary enzyme produced during this process. On a practical level, it can serve as an effective remedial technique.

Cometabolic processes work best when bacteria release enzymes during the degradation of a petroleum hydrocarbon. Researchers decided to



add petroleum hydrocarbons in the subsurface at Building 719 because none was present in significant quantity. After testing a variety of compounds, they selected propane as the easiest to introduce and the one that would not further degrade soil or groundwater quality. Three injection wells were installed in the test plot, and, in June 1998, a dilute mixture of propane of about 0.1–1 percent, well below its explosive limit, and air was pumped into the vadose zone-contamination at one location for 14 months. Prior to system start-up, a helium tracer test was done to make sure that injection wells and soil gas monitoring points were properly functioning and correctly positioned to recover unmetabolized propane vapors. The system was monitored every week.

When operations were halted in September 1999, a second set of soil samples was collected. As researchers waited for the TCE and DCE test results, they noticed that chloride concentrations in postremedial soil samples were high. This was a strong indication that the chlorine atoms had been stripped off the solvents and had joined with other ions (sodium and potassium) to form salt in the soil. If so, the bacteria would then be able to degrade the solvents actively. When the TCE and DCE data arrived, concentrations in most soil samples were below laboratory detection limits, and the effectiveness of a new remedial technology had been demonstrated. Cometary remediation has since been refined to the point where nonpetroleum-based electron acceptors can be added to the subsurface to induce the fortuitous reactions needed to metabolize chlorinated solvents. Such substrates (carbon sources) as lactate (sugar water), molasses, or ethanol are regularly introduced to contaminated soils to stimulate the enzyme production needed to break down TCE, tetrachloroethylene (PCE), and other chlorinated solvent compounds as part of the bioremediation process.

See also BIOREMEDIATION; CHLORINATED SOLVENTS; DCE; IN SITU GROUNDWATER REMEDIATION; PCE; SUPERFUND SITES; TCA; TCE; VOLATILE ORGANIC COMPOUND; WELLS.

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#### dust bowl Central United States 1930s Air Pollution

There have been only a few landmark, far-reaching environmental events that fundamentally changed the way people interact with their environment on a national and sometimes a global scale. The Donora, Pennsylvania, "Killer Fog," Exxon Valdez spill, and Love Canal pollution would be on most environmentalists' lists, along with such non-catastrophic events as Rachel Carson's book *Silent Spring* and Al Gore's popularization of the idea of climate change in *An Inconvenient Truth*. Despite the drama, tragedy, and pain that accompany most environmental disasters, only a few have directly affected more than just those living in the immediate area. These occurred in Bhopal, India; in 1952 in London (smog); in Chernobyl, Ukraine; in Linfen, China; and, during the 1930s, in the seven states of Oklahoma, Texas, Kansas, Colorado, Nebraska, South Dakota, and New Mexico, as well as parts of Canada, that collectively became known as the dust bowl.

#### BACKGROUND

When the vast plains of the central United States first opened to settlement, they were covered by deep-rooted natural grasses. These grasses clung tightly to the soil and had evolved to survive in the dry, cold, and windy conditions that were more typical for this part of the country than the wet, warm years of the mid-1800s. As farmers replaced the grasses with corn, soybeans, and alfalfa, the soil became less cohesive and attached to the land, so that, by the early 1930s, all that were required to create the dust bowl would be a drought and some wind.

For almost a century, the central United States enjoyed a period of above-average annual rainfall and fairly moderate temperatures. This, combined



Dust bowl cloud descends on Rolla, Kansas, April 14, 1935 (Franklin D. Roosevelt Presidential Library and Museum)

with the need for extra agricultural production that accompanied World War I, increased the demands on farmers to produce more food and to cultivate parts of their land that they would normally have left fallow. These areas were close to stream-banks, on steep ridges, or in areas covered with trees. This intense level of agriculture was combined with a number of very poor farming techniques including practicing no rotation of crops, plowing entire fields after each harvest, and allowing animals to graze off stubble and other crop residues.

### THE DROUGHT AND DUST STORMS

Although periods of low rainfall occurred in 1890 and again in 1910, nothing matched the enormous drop in precipitation that took place between 1926 and 1934. Areas that typically received 30–40 inches (76.2–101.6 cm) of rainfall per year were getting 40–50 percent of those amounts. Although the reasons behind this drought are not fully understood, recent research suggests a change in the jet stream and ocean currents may have made critical alterations to atmospheric circulation and moisture patterns. It was not until the early 1940s that precipitation levels in this area would again approach predrought levels.

As the fields dried, wind picked up the loose soil and moved it as massive, blowing clouds of dust. Without trees or grasses to hold the soil in place

or breaks to slow the wind, the blowing topsoil drifted like snow. In some places it settled over farms in layers of three feet (1 m) or more and turned once-productive fields into barren wastelands. In 1932, 14 dust storms were recorded on the plains, and, by 1933, the number was up to 38 storms. By 1934, more than 100 million acres (40.5 million ha) of prime farmland had lost all or most of the topsoil to the winds. The worst of the storms took place on April 14, 1935. This Black Sunday gave the dust bowl its name. With wind speeds of 60 miles per hour (96.6 km/h), dust blocked out the Sun, traffic came to a standstill on the roads, and a layer of dust that could be measured in inches penetrated into every home in the area, regardless of how well sealed. The Black Sunday storm blew eastward, depositing a layer of dust over Chicago that equaled four pounds (1.8 kg) for every person living there. It made its way into New England, New York City, and even Washington, D.C., where legislators experienced firsthand, although greatly diluted, what almost a third of the United States was going through. It was after this storm that an Associated Press reporter used the term *dust bowl* for the first time to describe what was happening to the central plains of the United States.

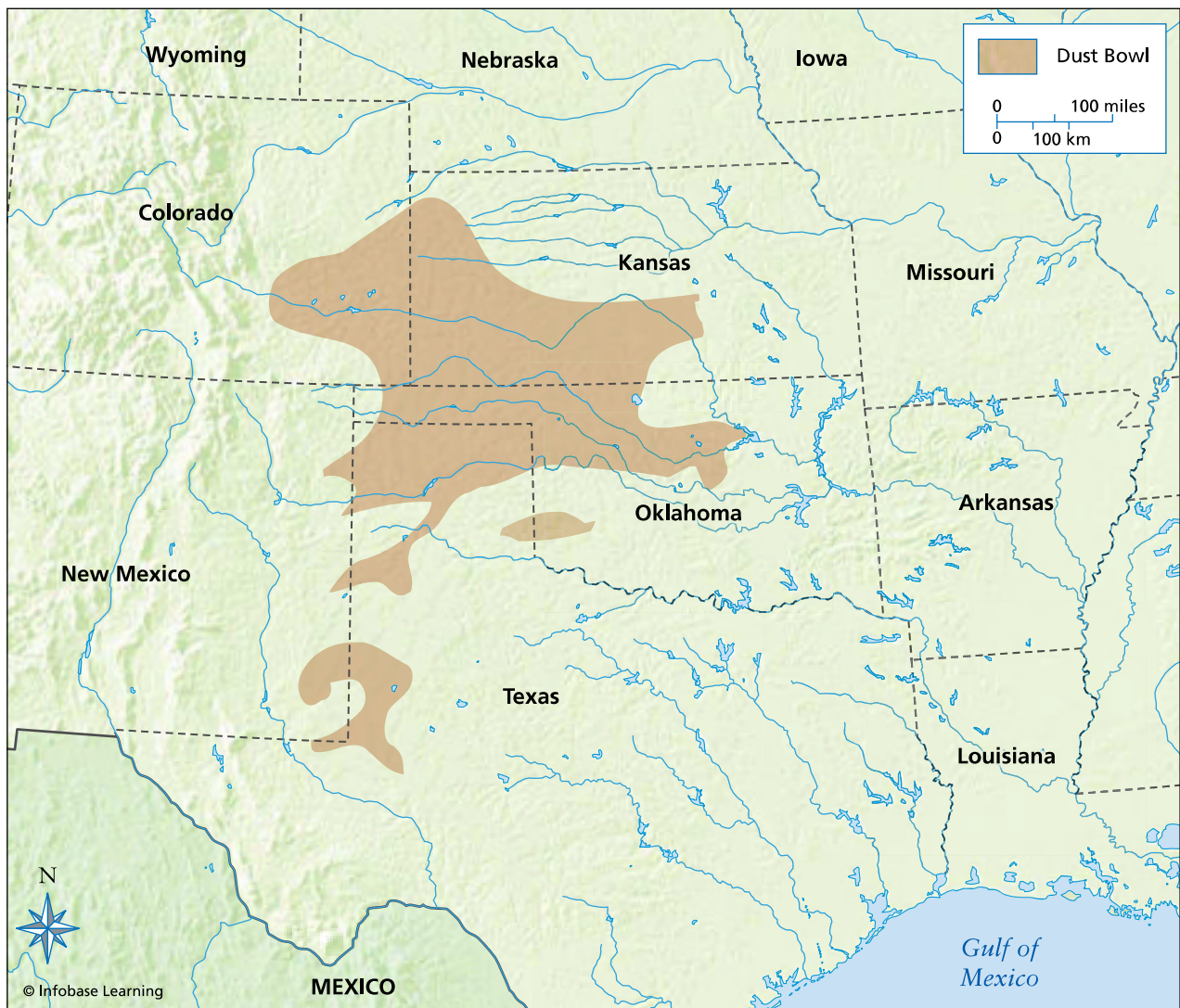
The human costs associated with the dust bowl were enormous. Many of the industrialized parts of the United States had begun to feel effects of the stock market crash of 1929 and the beginning

of the Great Depression, but the central plains had been somewhat insulated from that economic disaster. Farmers grew their own food and managed to maintain a reasonably unchanged, if unglamorous, lifestyle. As the dust bowl literally blew away their livelihood, and they could no longer make mortgage and tax payments, many had no choice but to abandon their homes and seek a new life somewhere else. The largest mass migration in American history took place as a result, and, by 1940, more than 2.5 million people had left their homes in the plains states and settled elsewhere. Some 15 percent of the people in Oklahoma left the state, many moving westward and settling in California. Other parts of the country tried to cope with the influx of dust bowl refugees, called “Okies,” even though they were from many different states. The Great Depression, however, was

in full swing, and these transient newcomers stressed local relief services and competed with long-time residents for jobs, often offering to work for greatly reduced wages.

### REMEDIAL ACTIONS

The government response was slow, but eventually political leaders realized that much of the country’s farmland was blowing into the Atlantic Ocean and started to take action. Congress formed the Soil Conservation Service (now the Natural Resource Conservation Service) in 1935, and it began to study and implement cultivation techniques to reduce topsoil erosion by wind and water. As President Franklin Roosevelt’s New Deal legislation began to pass, the Works Progress Administration (WPA) and other



Map of the south-central United States showing the locations of dust storms or dust conditions during March 1936



newly formed government agencies began to provide emergency supplies, cash, and livestock feed, and transport to maintain the basic functioning of livelihoods for farmers and ranchers. Health care facilities were established and medical supplies provided to meet emergency medical needs of those communities most deeply affected. The government set up reliable markets for farm goods, imposed higher tariffs on imported foodstuffs, and established loan funds for farm market maintenance and business rehabilitation. By 1934, congressional appropriations for drought relief exceeded \$500 million.

As the 1930s came to an end, additional soil conservation measures and policies were implemented. Water supply and irrigation systems were upgraded, and a federal crop insurance program was instituted. The average size of farms increased, and low-yielding, ecologically sensitive, and buffer lands were removed from production. These and other soil conservation programs helped to mitigate the effects of future droughts and establish a pattern of soil conservation measures that made the United States the most agriculturally productive country in the world.

### CURRENT CONCERNS

The agricultural leadership that the United States has achieved is being threatened. The highly mechanized and chemically intensive tools and techniques that were developed in the 1930s and 1940s in response to the dust bowl are now being challenged as concerns increase over the “carbon footprint” of farms and the effects of pesticides and fertilizers on

human health and the environment. This concern is occurring at a time when growing populations, which are expected to double by the end of the 21st century, will place increasing demands on agricultural resources. New techniques such as no-till farming, genetic manipulation of high-yield cereal hybrids, and organic growing methods are currently under development and, in combination with sustainable soil management practices, may offer a way to secure a safe and reliable food supply.

*See also* BHOPAL AIR POLLUTION DISASTER; CARSON, RACHEL; CHERNOBYL NUCLEAR DISASTER; DONORA KILLER FOG; EXXON VALDEZ OIL SPILL; GORE, AL; LOVE CANAL.

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# E

**earthquakes** In addition to being devastating in terms of loss of life and property, strong earthquakes can produce an environmental impact that is felt for years. In many cases, the environmental effects pale in comparison to the damage and death from the earthquake itself and as such are overlooked. Typically, only the contamination of the water supply and resulting disease are ever described in the media. One reason for this lack of comprehensive reporting may be that the United States has been spared any disastrous earthquakes in recent history. Just as long-term effects of environmental contamination from the collapsing World Trade Center in the 9/11 disaster are now being felt by those who participated in the recovery efforts and will appear in the rescue workers of Hurricane Katrina, the same health consequences commonly impact those who have experienced a major earthquake.

## MAJOR EARTHQUAKES

Scientists classify an earthquake by its magnitude, which basically translates into its strength. Early efforts to measure the power of an earthquake were based upon damage to structures and the perception of witnesses. This measure is now termed intensity rather than magnitude, and, at present, the Modified Mercalli scale is the accepted method of measuring the intensity of earthquakes. It rates intensity from I to XII and reflects the magnitude as well as location of the earthquake in terms of geologic materials, building construction, and population density. Although magnitude is used to define an earthquake, for purposes of pollution, intensity, or

the damage caused at the surface, may be the more important designation. Magnitude measures the amount of energy released in an earthquake through the use of instrumentation-based observations of the energy of waves as they pass through the Earth. The initial and most famous catalogue of these ground motions is the Richter scale, which was devised in 1929 after the first reliable seismographs had been developed. The Richter scale is a logarithmic scale based upon the measured amplitude of the strongest waves released by the occurrence of an earthquake and taking into account the types of rock and soil through which they pass. In an attempt to characterize the total energy released by the earthquake better, the moment magnitude scale was developed; it uses ground acceleration or the movement caused as the waves pass through the Earth. Moment magnitude is the current standard for earthquake strength. A new technique being considered for use as a measure of earthquake intensity is Shakemap. Developed by the U.S. Geological Survey, Shakemap measures intensity from ground acceleration over a given area during a major earthquake.

There are numerous major earthquakes every day all around the Earth. The vast majority of these cause very little environmental pollution. They occur in remote areas or beneath the ocean with deep enough foci that they do not generate tsunamis. Although major earthquakes that occur under these conditions typically do not threaten population centers, others closer to developed areas that have intensities above IV or V on the Modified Mercalli scale may be causative or contributing factors for certain types of pollution events. Such events may be the destruction of human structures or other types of damage.

### PARTICULATE HAZARDS

The Lisbon earthquake of 1755 is reported to have raised so much dust that it blocked out the Sun. This is not the only historical earthquake that is reported to have raised surface dust into the air. In this case, however, blocking out the Sun required a large, dry, dusty area that would allow the shaken ground particles to be quickly dispersed into the atmosphere. A description of the Assam 1897 earthquake in which rocks on roads were said to vibrate “like peas on a drum” illustrates the effect of surface waves on particles on the surface. As the energy waves released by an earthquake pass through an arid, unvegetated region, the loose soil and silt at the surface are disturbed and thrown into the air. This is similar to the way a car driving down a dry, unpaved road leaves billowing clouds of particulate behind it. Many major earthquakes occur in moist and vegetated areas, and significant amounts of dust generation are not usually associated with them.

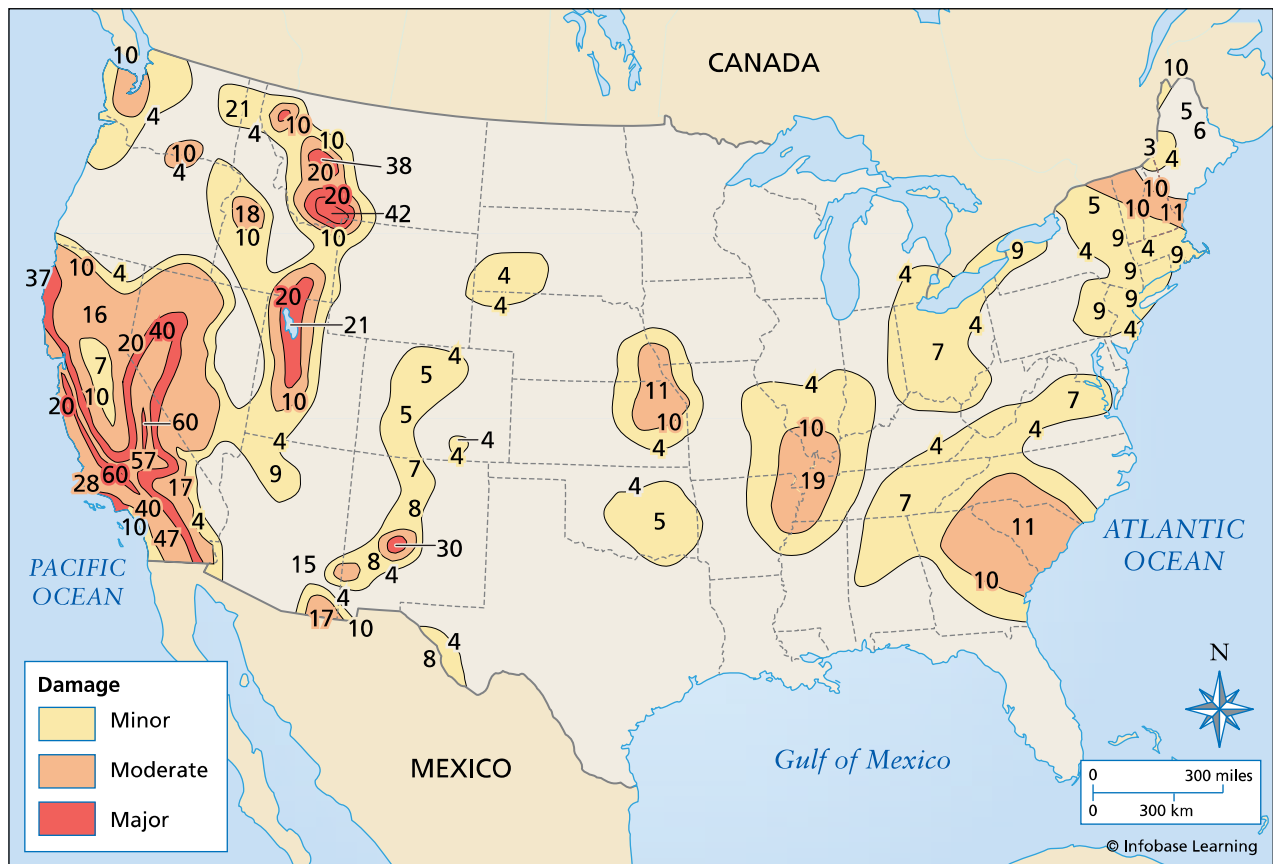
Collapsing buildings during an earthquake also typically raise significant dust. This can be seen under nonearthquake conditions when large build-

ings are demolished for urban renewal. A large dust cloud is typically emitted when they are knocked down or blown up. Considering that old buildings may contain asbestos, lead paint, lead solder, and fiberglass, among other materials, this cloud could well be a health hazard. The dust from both of these sources is typically particulate matter with a diameter of 10 microns or less (PM10), which is considered a respiratory irritant and health hazard.

One of the main dangers of earthquakes in the past was fire. It is still a threat today but not nearly as dire as previously. In historic times, cooking was done on fires, in stoves, or on braziers; lighting was provided by candles and oil lamps; and heating was produced by coal or wood stoves or furnaces. Seismic waves commonly toppled these sources, and the old wood houses of the times were quickly engulfed in flames. As in all earthquakes, buildings tend to topple into the street when they are destroyed. This results in particularly slow going for fire engines and fire brigades. Before modern hydrant systems, horses had to pull tanks of water to the fire, and this small amount of water was dumped on the fire without pressure. In many of the most famous historical



Black smoke from an earthquake-induced fire in Kobe, Japan, 1995 (© Reuters/CORBIS)



**Earthquake risk map for the continental United States with the probability for earthquakes and the expected amount of damage indicated by shading**

earthquakes, the main source of destruction was the fire rather than the seismic waves. In the great Kanto earthquake of 1923 that destroyed Tokyo, Japan, fire was, by far, the most devastating part. More than 142,000 people perished in this disaster, including more than 35,000 at one time in a single sweeping firestorm. These unfortunate souls had survived the seismic waves and had made their way to a military park where a relief area had been erected when the storm struck. There were reports of fire tornadoes because the heat was so intense.

The most famous fire caused by an earthquake in the United States was the one caused by the great San Francisco earthquake of 1906. It basically destroyed the entire city. Fire started in several areas at the same time and spread unchecked until there was no way it could be controlled. The army attempted to bomb a firebreak around the inferno but wound up destroying structures that might have survived, igniting new fires in areas that had been spared the main fire, and causing very unsafe conditions for the survivors. The most striking feature of most photographs of the San Francisco earthquake is the enormous black clouds rising over the city. This

smoke was not only loaded with particulate but with polycyclic aromatic hydrocarbons (PAHs), benzene methylethyl ketone (MEK), and other dangerous chemicals, depending upon what was also burning at the time. This cloud was composed of both PM<sub>10</sub> and PM<sub>2.5</sub> (particulate matter with a diameter of 2.5 microns or less).

### DISRUPTION OF UTILITIES

Both direct surface movement and seismic waves can sever all forms of utilities during a major earthquake. The most obvious problem is the severing of natural gas lines. Gas leaks can occur throughout the affected city and not be stopped until the system is shut down. Methane can cause significant adverse health effects, particularly in the respiratory system, and even lead to death. It is also highly flammable, representing a great risk for explosion. In areas of oil production, this danger is even more pronounced if oil pipelines are severed. Spilled oil can contaminate surface water bodies and other low-lying features such as wetlands, lakes, or ponds and present a fire hazard, as well.

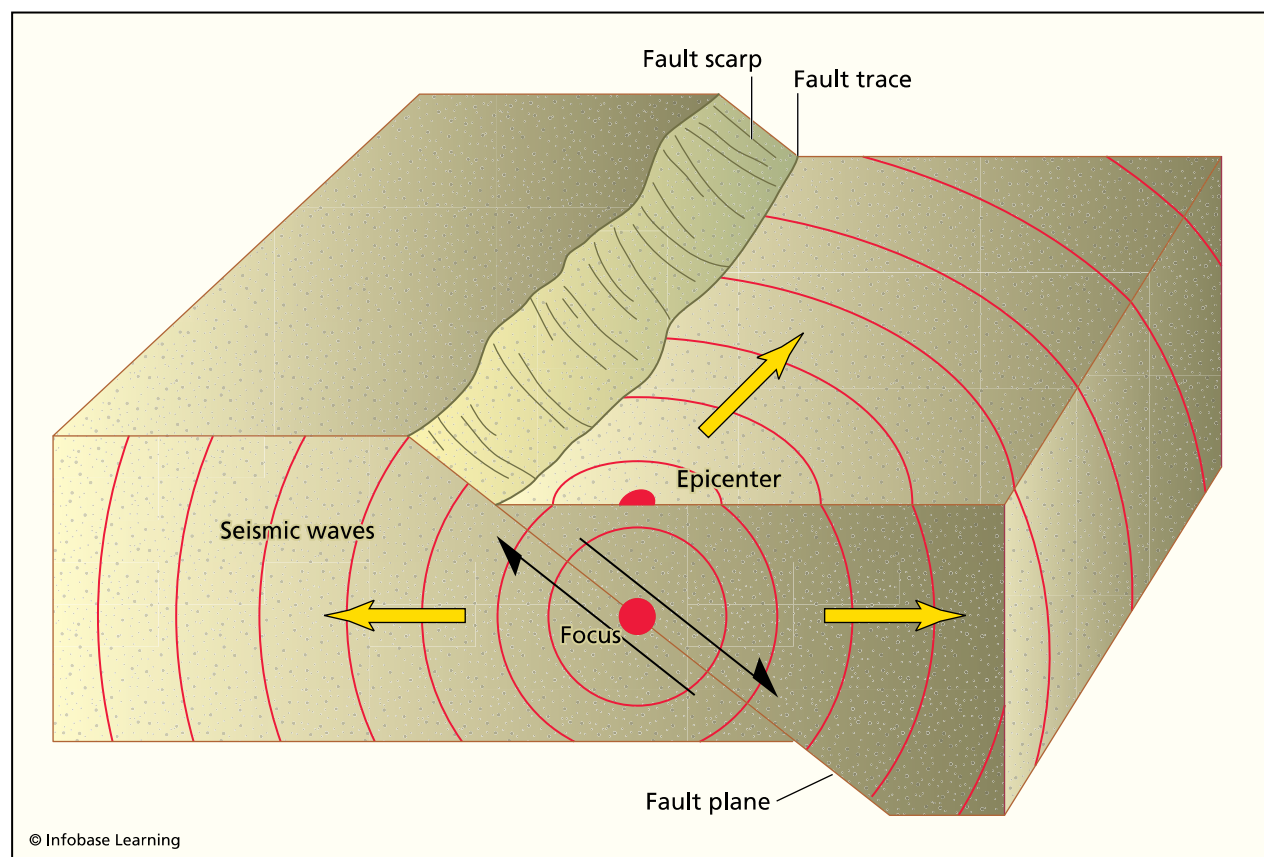
The most reported environmental problem after an earthquake is the cutting of water lines by the shift in ground position. Without a source of fresh water, remaining supplies quickly dwindle and become contaminated with bacteria. Disease that commonly follows major disasters can be directly related to problems with water supplies. This contamination is usually exacerbated by damage to another public utility, sewer lines. They can rupture as easily as the water mains and contaminate any surface water body or low-lying feature. The spilling of untreated sewage can take years to repair. Even well water can be contaminated during earthquakes. Seismic waves typically drive water upward in the soil during earthquakes, resulting in liquefaction, in which soil begins to behave (flow) as a liquid. This vertical movement of groundwater can cause it to become turbid and unpotable as a result of excessive concentrations of silt suspended in it.

### CHEMICAL SPILLS

Any stored chemical is a potential environmental disaster during an earthquake. Cities with oil refin-

eries or chemical industries are particularly vulnerable. Refineries contain enormous amounts of oil stored in large tanks connected by pipelines in various stages of chemical reaction. Refineries are also commonly close to major water bodies, where workers can off-load crude oil from tankers. Serious spills are common at these types of facilities even without an earthquake, and several coastal zones in northeastern New Jersey, near Baton Rouge on the Mississippi River in Louisiana, and near Houston, Texas, are profoundly polluted as a result. Either fortunately or as a result of strictly enforced local building codes, most oil-handling facilities are within seismically quiet regions. If an earthquake were to strike any of these industrial plants, spills from the tank and pipeline ruptures would be catastrophic. These areas also contain major chemical industries that work with refinery products and that maintain large supplies in tanks, which are prone to rupture, as well.

In many cases, the oil industry is aware of the potential damage to pipelines and storage tanks. The huge trans-Alaskan oil pipeline crosses some major active faults with a capacity for surface ruptures. In



**Block diagram of a fault on which an earthquake is taking place: The concentric spheres emanating from the focus illustrate the seismic wave fronts.**



anticipation of potential earthquake activity, facility designers and operators have taken great pains to guard against ruptures of the pipeline, especially in its joints and surface mounts. There are also shutoff valves at regular intervals to halt the flow in the event of emergency. The system was put to the test on November 3, 2002, when a magnitude 7.9 earthquake occurred on the Denali fault, which crosses the pipeline. This earthquake produced a surface rupture 209 miles (335 km) long with up to 29 feet (8.7 m) of lateral offset. Shaking lasted 90 seconds and produced a band of landslides 16–24 miles (9.6–14.5 km) long with fissures large enough to swallow a bus. Under the pipeline, the ground shifted more than 14 feet (4.3 m), and shaking was intense. Yet the pipeline did not rupture, attesting to the excellence of its engineering.

### NUCLEAR POWER PLANTS

Fortunately, no earthquakes have caused a real disaster at a nuclear power plant, although such an event is not out of the realm of possibility. The danger with nuclear power plants is that they require large amounts of water for cooling, and, as such, are commonly located on rivers. The faulting process breaks up rocks, allowing them to be easily removed (eroded) by wind, water, or ice along the fault line, forming a low valley. Rivers follow valleys and, as such, commonly sit on faults. This natural phenomenon has not been unnoticed by the U.S. Nuclear Regulatory Commission, and areas where power plants are proposed undergo a rigorous geological evaluation before a permit is granted. Even after they are operational, close monitoring and reevaluation are common. Thanks to the caution exercised by nuclear power plant owners and government regulators, there has never been an environmental disaster caused by earthquake-induced damage at a nuclear power plant. This, however, may also reflect a certain amount of luck.

The Indian Point nuclear power plant sits on the Hudson River, just north of New York City. It is an old plant, well past its expected life span. Some scientific studies have suggested that the course of the Hudson River is controlled by a covered fault that lies in the base of the river. The power plant is located at the point where the Ramapo fault, perhaps the most prominent fault in New Jersey, crosses the river. The trace of the fault lies right under the power plant. It is believed that the Ramapo fault is active, and there

certainly are numerous small earthquakes along the Hudson River. The largest recent earthquake was in 1884 and was estimated at a 5.2 magnitude, but it was to the south in New York harbor. If an earthquake of magnitude 5.2 or greater occurred under the Indian Point plant, would it cause a meltdown? There are 1.5 million people in the counties around the plant, and the radioactive waste would flow down the river or could be blown by prevailing winds into New York City. It could be the greatest human disaster ever. It is not the only example of a nuclear power plant in a precarious location.

There have been cases when nuclear power plants have suffered damage from earthquakes and even leaks. The most recent incident was the result of a magnitude 6.8 earthquake on July 16, 2007, in Niigata, Japan. The earthquake damaged the Kashiwazaki Kariwa nuclear power plant, which is the largest in the world. It took two hours to extinguish the transformer fires that resulted from shaking, and approximately 315 gallons (1,192 L) of radioactive water spilled into the Sea of Japan. There was no real danger that the plant would go into a catastrophic meltdown, but Japan is capable of much stronger and more damaging earthquakes.

### TSUNAMIS

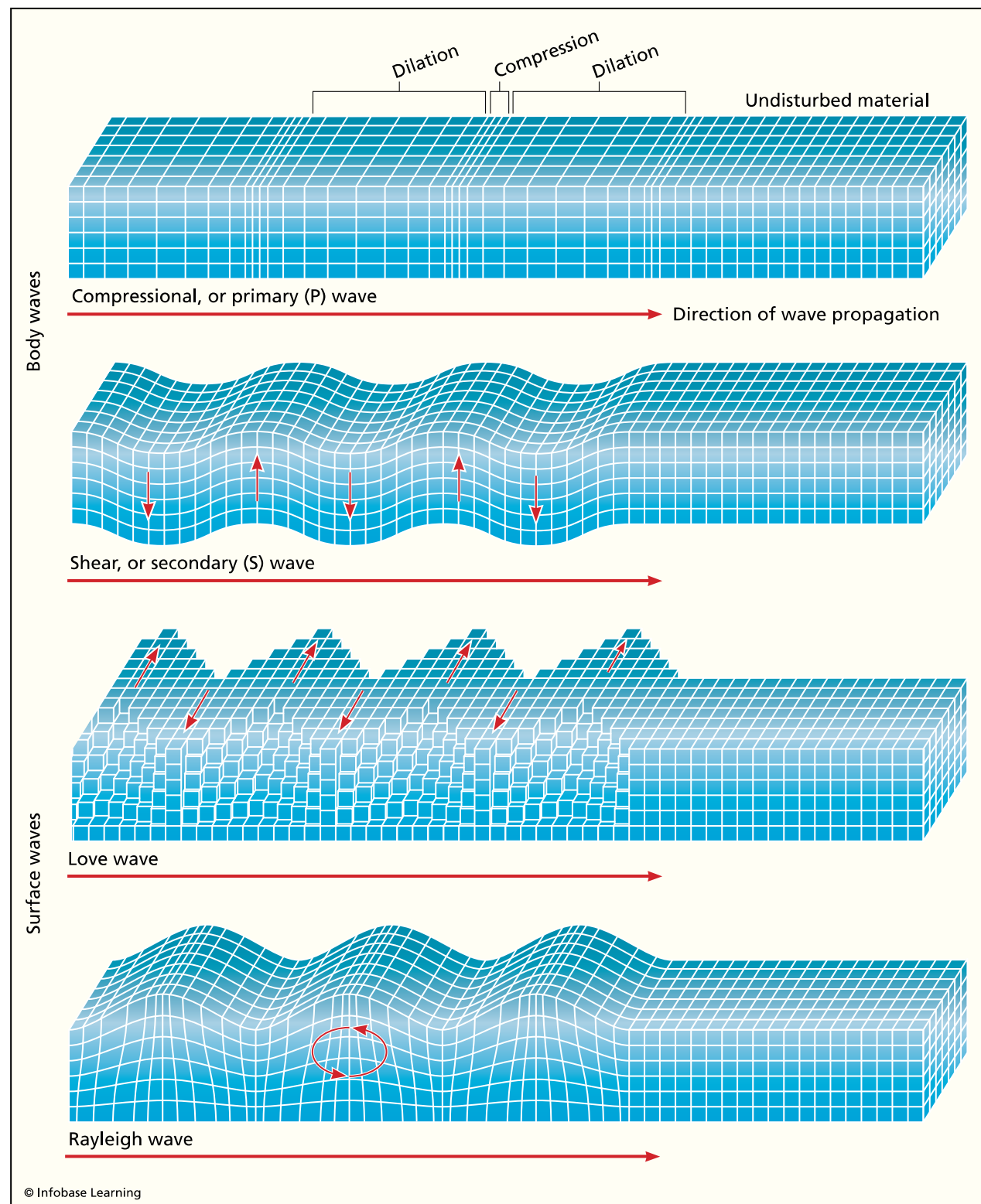
Earthquakes produce a series of life-threatening hazards, the most fearsome of which is a tsunami. If there is uplift of the sea bottom or a submarine landslide occurs, the water column does not react quickly and there may be a temporary “step” on the surface of the ocean. Water tends to seek its own level (remain flat and smooth) and cannot have an abrupt elevation change. A tsunami is the active releveling of sea level. Tsunamis travel at high velocities of 400–700 miles (644–1,127 km) per hour across the open ocean. Although some movies would have people believe that they are huge in the open ocean, this is simply not true. They are no more than three feet (0.9 m) high with a wavelength so long (approximately 328 feet [100 m]) that ships are usually not able to detect them. The word *tsunami* means “harbor wave” in Japanese, because it rises up out of nowhere in a harbor as the wave enters shallow water.

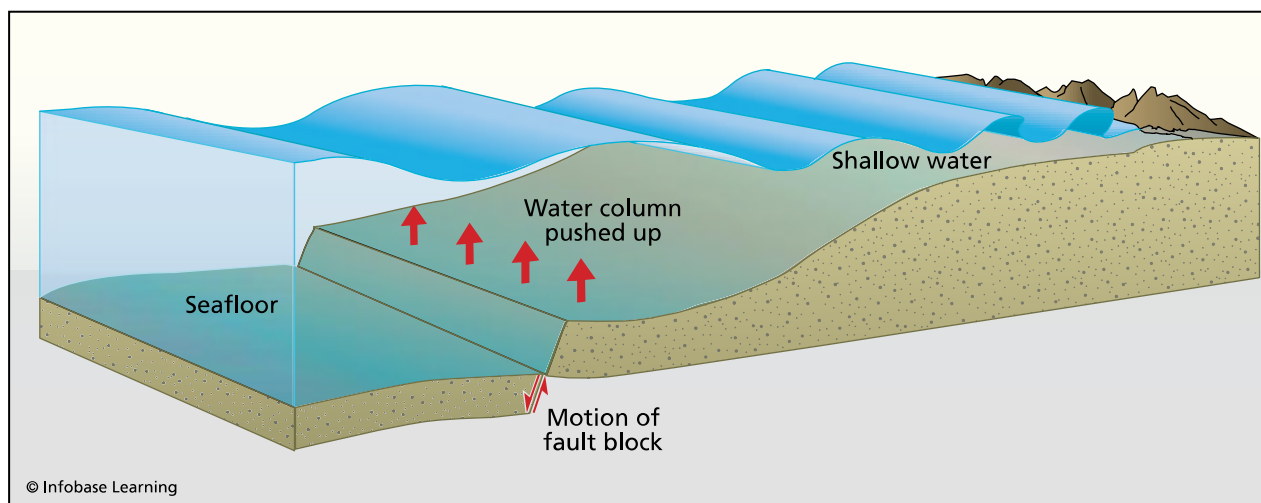
The common perception is that tsunamis are dangerous because they drown people. In reality, although people can drown, too, the real danger is that the waves hit the shore still traveling at 50–60

*(opposite page) Diagrams showing the response of rocks to different types of seismic waves passing through them. The distortion caused by the waves passing through is elastic in that no permanent change in shape takes place. P- and S-waves travel throughout the body of the Earth, but Love and Rayleigh waves only travel along the surface. Surface waves cause the most damage.*

miles (80–97 km) per hour in comparison with the typical wave speed of five to 20 miles (8–32 km) per hour. Depending upon their height, they can crush shoreline structures including chemical tanks and

toss ships, including tankers, onto the shore and rupture them. The massive wall of salt water can penetrate one mile (1.6 km) or more inland, contaminating all surface water and even groundwater





**Block diagram showing the generation of a tsunami through uplift of the seafloor during an earthquake. The uplift causes the overlying seawater to be uplifted as well, and the tsunami is the releveing of the ocean surface. This is by far the most common way tsunamis are generated.**

supplies in the process. The great weight of the water overwhelms all sewer systems, and sewage is pushed to the surface. Debris is strewn everywhere, and decaying corpses of humans and animals spread disease to the survivors. Vegetation is stripped away, and the salt inhibits recovery for years. Environmental damage in Thailand and Indonesia in the wake of the December 26, 2004, Banda Aceh earthquake and tsunami will take many years to overcome, far longer than rebuilding the infrastructure and repopulating the area.

See also BENZENE; HURRICANE KATRINA; MEK; PAH; PARTICULATE; RADIOACTIVE WASTE; SALT-WATER INCURSION; WORLD TRADE CENTER DISASTER.

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***E. coli*** *E. coli* is short for *Escherichia coli*, a group of bacteria with hundreds of strains. The vast majority of them are harmless. At present, there are four strains of enterovirulent *E. coli* that are known to cause gastroenteritis in humans. These four are designated as the EEC group. The most virulent of this group is the enterohemorrhagic *E. coli* (EHEC) strain, known as *E. coli* 0157:H7. When an outbreak of *E. coli* is reported in the news, it is this strain alone that is responsible for the disease and possible death. *E. coli* is the leading cause of food-borne illness. A 1999 Center for Disease Control and Prevention (CDC) survey found 73,000 cases of infection and 61 deaths in the United States per year, though since then there has been a 29 percent reduction in cases. Although *E. coli* outbreaks result primarily from infected food, they can also affect water supplies. It is for this reason that *E. coli* is considered a pollutant.

#### GROWTH AND OCCURRENCE

*E. coli* occurs naturally in the intestines of healthy cattle, deer, goats, and sheep and can be found on most cattle farms and petting zoos, among other places. It can contaminate the ground, railings, feed bins, and fur of the animals. It can contaminate meat during slaughter and milk that has contact with a cow's udders. It is removed from milk during pasteurization, but it may remain in meat and especially ground beef even after it has been sent to market. *E. coli* cannot be detected on meat and can only be killed if the meat is cooked to a high enough temperature. It can also occur in beans and alfalfa sprouts, lettuce, spinach, salami, and unpasteurized

milk and juice. Even extensive washing may not remove the *E. coli* from contaminated produce, and it requires a very small amount to infect humans. It can also be passed on hands that have been in contact with waste or contaminated foods.

Cattle manure and other animal wastes typically contain abundant *E. coli*. Manure can be a powerful contaminant of the environment. Streams, lakes, and rivers can be contaminated with *E. coli* during precipitation and melting events through runoff. Streams that pass through pastures are commonly contaminated, and irrigation of fields that use manure as a fertilizer can also result in contamination. Sewage spills and overflowing septic systems can also introduce *E. coli* into the environment. Even pools can be contaminated by young swimmers, as well as currently infected older swimmers, for up to 14 days after the symptoms have subsided.

### HEALTH EFFECTS FROM EXPOSURE

Symptoms of *E. coli* appear after two to eight days (average three to four) of exposure to the bacterium. Once inside the human digestive system, it produces large amounts of one or more strong toxins (verotoxin [VT] and shigalike toxins) that are very damaging to the lining of the intestines. The disease that is produced is hemorrhagic colitis, and it is characterized by severe abdominal cramping and diarrhea that becomes bloody in most cases. This condition may be accompanied by vomiting and low-grade fever in some cases. The illness runs its course in five to 10 days, depending upon severity.

In some cases, especially in children less than five years of age and elderly adults, the disease may progress into a severe complication, called hemolytic uremic syndrome (HUS), which occurs in about 8 percent of reported cases of *E. coli*. In this complication, red blood cells are destroyed and the kidneys fail among other symptoms. Some people experience other severe consequences of HUS such as blindness, paralysis, lifelong kidney malfunction, and intermittent failure or complete loss of kidney function. In about 3–5 percent of HUS cases, the result is death. If HUS is accompanied by fever and neurologic symptoms in elderly patients, the condition is called thrombotic thrombocytopenic purpura (TTP), which can have a mortality rate as high as 50 percent.

### REGULATIONS ON HUMAN EXPOSURE

Under the Safe Drinking Water Act, the U.S. Environmental Protection Agency (EPA) limits the total coliforms (including *E. coli*) in drinking water to less than 5 percent with a goal of 0 part per mil-

lion (ppm). They further require the regular testing of public water supplies up to 480 times per month for the largest population served but only once per month for the smallest. Private wells are only tested at the discretion of the owner. Approved systems to disinfect public water supplies include chlorine, ultraviolet radiation, and ozone, all of which will destroy *E. coli*. For individuals to ensure the destruction of *E. coli* in drinking water, they must boil it for at least one minute.

### E. COLI OUTBREAKS

The first identified outbreak of *E. coli* 0157:H7 was in August 1982, when the Centers for Disease Control and Prevention identified 25 cases linked to tainted hamburger meat. The largest outbreak of *E. coli* occurred from November 15, 1992, to February 28, 1993, in the states of Washington, Idaho, California, and Nevada. There were more than 500 laboratory confirmed cases and four deaths associated with this outbreak, and the culprit was, once again, contaminated ground beef. Included in this group were 230 confirmed cases and 80 pending cases of infection from hamburgers consumed at a fast-food restaurant chain in Washington in January 1–29, 1993. Two cases of *E. coli* from contaminated surface water occurred in 1999, when one group of people became sick from drinking water in Washington County, New York, and another group became sick from swimming in contaminated water in Clark County, Washington.

See also WATER POLLUTION.

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**EDB (1,2-dibromoethane)** 1,2-Dibromoethane (EDB) was very widespread in the United States for many years by virtue of being an additive to leaded fuels. It was emitted from tailpipe exhaust but was banned in the United States after it was found to be highly toxic to mammals, including humans, carcinogenic, and very persistent in the natural environment. However, it is still used in many countries as a gasoline octane booster. For these reasons, and although EDB is present in only 27 of the first 1,416 U.S. Environmental Protection Agency (EPA)–designated Superfund sites where tested, it is still rated number 35 of the 275 compounds on the 2005 CERCLA Priority List of Hazardous Substances. EDB is also known as DBE, alpha- and beta-dibromoethane, dibromoethane, ethylene bromide, glycol bromide, glycol dibromide, and sym-dibromoethane and sold commercially as Bromofume, Celmid, Dibrome, Dowfume, EDB-85, Fumo-Gas, Kopfume, Nephis, and Soilfume. EDB also was commercially used as a pesticide, but this application has also been banned because of the threat it poses to human health and the environment. Now the danger it represents is related to residues in soil and groundwater from prior uses and imported products from countries where it has not been banned.

### PROPERTIES, USE, AND PRODUCTION

EDB is primarily a synthesized substance, but it also occurs naturally in the oceans, where small amounts of it are produced by algae and kelp. It is a halogenated hydrocarbon that had many applications in the past but is sparsely used now. In pure form, EDB is a clear, colorless liquid with a sweet, chloroformlike odor and a tendency to evaporate quickly. The annual production of EDB in the United States peaked at 332 million pounds (151 million kg) in 1974. Its primary use was as an antiknock additive to leaded gasoline. It was used as a scavenger for lead so that it would be removed from the engine after combustion. Even as late as 1978, more than 90 percent of all EDB used in the United States was for this purpose. Leaded fuel, however, was being phased out in the 1970s, and, by 1982, the annual domestic production of EDB was down to 169.8 million pounds (77.2 million kg). The other major use of EDB as a pesticide was as a nematocide for agricultural crops and lawns (especially golf courses) and as a fumigant for a variety of fruit, vegetable, and grain crops (barley, maize, rice, sorghum, rye, oats, and wheat), especially against fruit flies. It also was used to control bark beetles in logs, moths in stored furniture and clothing, termites under concrete slab foundations

and porches, Japanese beetles in ornamental trees, and wax moths in honeycombs. An EPA ban on these uses was enforced in 1984, further reducing the remaining production. Similar legislation in other countries at that time also reduced exports. In 1978, U.S. exports of EDB topped 84.8 million pounds (38.4 million kg), but by 1981 they had declined to 29.8 million pounds (13.5 million kg). By 2000, exports were down to 5.4 million pounds (2.5 million kg). Currently, EDB is used solely in the synthesis of other chemicals and as a solvent for resins, gums, and waxes in the United States.

### ENVIRONMENTAL RELEASE AND FATE

EDB was primarily a nonpoint source pollutant, released from automobile exhaust and pesticide usage. It was and is a point source pollutant through releases from manufacturing, transport, storage, and waste facilities. Vegetation takes up small amounts of EDB from the soil and groundwater, and fumigated food products may contain EDB residues for up to six to 12 weeks. In surface water, EDB mainly evaporates, with an estimated removal half-life of a little more than one day in rivers and five days in lakes. If released into the soil, EDB will degrade by exposure to sunlight or by microbial action and/or evaporate quickly near the soil surface. Once beneath the surface, it is much more persistent, depending upon soil type. It remains in topsoil by tightly binding to organic particles and slowly biodegrading, but it moves quickly out of sandy soils. An estimated removal half-life for field conditions is 100 days, although some studies have found residues persisting for two to as much as 20 years or more, depending upon conditions. Otherwise, about 90 percent of that released slowly leaches into the groundwater system at a proportional rate to temperature (faster at 77°F [25°C] and much slower at 41°F [5°C]) and soil conditions. Once in groundwater, it is even more persistent—for months or years. In one study in New Jersey in 1977–1979, EDB was found in 34 of 421 groundwater samples and 11 of 175 surface water samples.

EDB has mainly been released into the air either by fumigation, evaporation, or automobile exhaust. It breaks down slowly in air by reaction with hydroxyl radicals and photochemical reactions. Removal time is about four to five months, allowing widespread transport in the atmosphere. Both EDB and its breakdown products can cause significant damage to the stratospheric ozone layer. Some studies suggest that these bromine compounds of EDB can be even more efficient than the chlorine-based CFCs (chlorofluorocarbons) in removing ozone.

Industrial release of EDB into the environment was 99,418 pounds (45,190 kg) in 1988 but decreased to 10,054 pounds (4,570 kg) by 1998. By 2005, the industrial release totaled 5,563 pounds (2,259 kg) with a continuous downward trend, with the exception of 1999, in which there was a bad spill.

### HEALTH EFFECTS FROM EXPOSURE

Exposure to EDB typically results in numerous adverse health effects. EDB is considered to be highly toxic (EPA toxicity class I), and acute exposure to it produces rapid breathing, nausea, vomiting, diarrhea, headache, lung damage, clouding of the corneas, blistering of the skin, and, at high dosage, ulcers of the mouth and stomach, liver and kidney damage, and death. Long-term chronic exposure can produce damage to the liver, kidneys, adrenal glands, and testes as well as weight loss, chronic bronchitis, pneumonia, headaches, and depression. It also weakens the immune system of the lungs. Reproductive damage is especially pronounced in males, but EDB can also cause birth defects and delayed brain development and motor coordination in offspring.

The U.S. Department of Health and Human Services classifies EDB as reasonably anticipated to be a human carcinogen, and the International Agency for Research on Cancer classifies it in group 2A, probably carcinogenic to humans. It has been shown to produce numerous types of cancer in laboratory animals including in the nasal cavity, esophagus, alveolar-bronchiolar system, and lungs through inhalation; forestomach, stomach, kidneys, spleen, and liver through ingestion; and in the mammary glands, adrenal cortex, and thyroid glands through any exposure. There is some evidence that EDB is mutagenic in several systems including sister chromatid exchange, mutations, and unscheduled deoxyribonucleic acid (DNA) synthesis, but it has not been shown to cause genetic damage in humans in most studies.

### REGULATIONS ON HUMAN EXPOSURE

As a result of the threat to human health and the environment, exposure of the general public and workers to EDB is regulated by the federal government. The EPA limits EDB in drinking water to a maximum of five parts per billion (ppb) under the Safe Drinking Water Act. They recommend a maximal exposure of 8 ppb for any 10-day period. The Occupational Safety and Health Administration (OSHA) has set a permissible exposure limit (PEL) of 20 parts per million (ppm) of EDB in workplace

air over an eight-hour-day, 40-hour workweek, with a maximal peak level for any five minutes of 50 ppm. The National Institute of Occupational Safety and Health (NIOSH) set their recommended exposure limit (REL) at 45 ppb and their immediately dangerous to life and health (IDLH) limit to 100 ppm in workplace air. The EPA National Occupational Exposure Survey of 1981–1983 estimated that approximately 9,000 American workers were potentially exposed to EDB on a regular basis. Besides the United States, EDB has been banned for agricultural purposes in Egypt, Japan, Kenya, the Netherlands, Sweden, and the United Kingdom, among others.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**Edwards Aquifer** Located in south central Texas, Edwards Aquifer is one of the most productive aquifers in the United States. It is largely a limestone aquifer, which primarily serves the cities of Austin and San Antonio, providing water to more than 2 million people. This important aquifer is unique in its storage capacity, flow characteristics, water producing capability, and efficiency in

recharge (allowing surface water to enter the aquifer). It is for these same reasons that the Edwards Aquifer is very sensitive to pollution and is encountering increased environmental pressures with increased population growth.

### LOCATION AND SIZE

The Edwards Aquifer is contained within the limestone of the Edwards Formation. It is a honeycombed rock unit from extensive karst development that ranges from about 300 to 500 feet (92 to 154 m) thick. The effective area of the aquifer and catchment forms a 160-mile- (256-km-) long arc that extends through 13 Texas counties and ranges in width from five to 40 miles (8–64 km). The total area of the aquifer and catchment is about 8,000 square miles (20,480 km<sup>2</sup>). The aquifer area is divided into three zones, the contributing zone, the recharge zone, and the artesian zone. The contributing zone, or catchment area, is on the Edwards Plateau in the Texas Hill Country and covers about 4,400 square miles (11,264 km<sup>2</sup>). It is from this

high area that the water develops its head, or the pressure that causes it to move through the ground. The recharge zone is south of and downslope from the catchment area and is enhanced by the Balcones fault zone, which has fractured the rocks, allowing quick infiltration of surface water into the underground system. Below and to the south is the artesian zone, where the spectacular flow rates occur. Farther south, the water in the aquifer is saline and not potable. The usable aquifer area is about 3,600 square miles (9,215 km<sup>2</sup>), including 1,250 square miles (3,200 km<sup>2</sup>) of the recharge zone.

### WATER FLOW

The aquifer is recharged mainly by influent streams; a surface water reservoir, called Medina Lake; and even some from the Trinity Aquifer, another groundwater source. In the area where most of the recharge takes place, the Edwards Aquifer contains numerous sinkholes and is unconfined (open to the surface). It behaves as a typical shallow aquifer here, receiving water from surface precipitation and not under artesian pressure or having any appreciable springs. There is a transition area between the recharge and the artesian zone that has some characteristics of each. The artesian zone occurs because the aquifer unit is confined between impermeable layers, thus allowing the steep gradient to increase the water pressure.

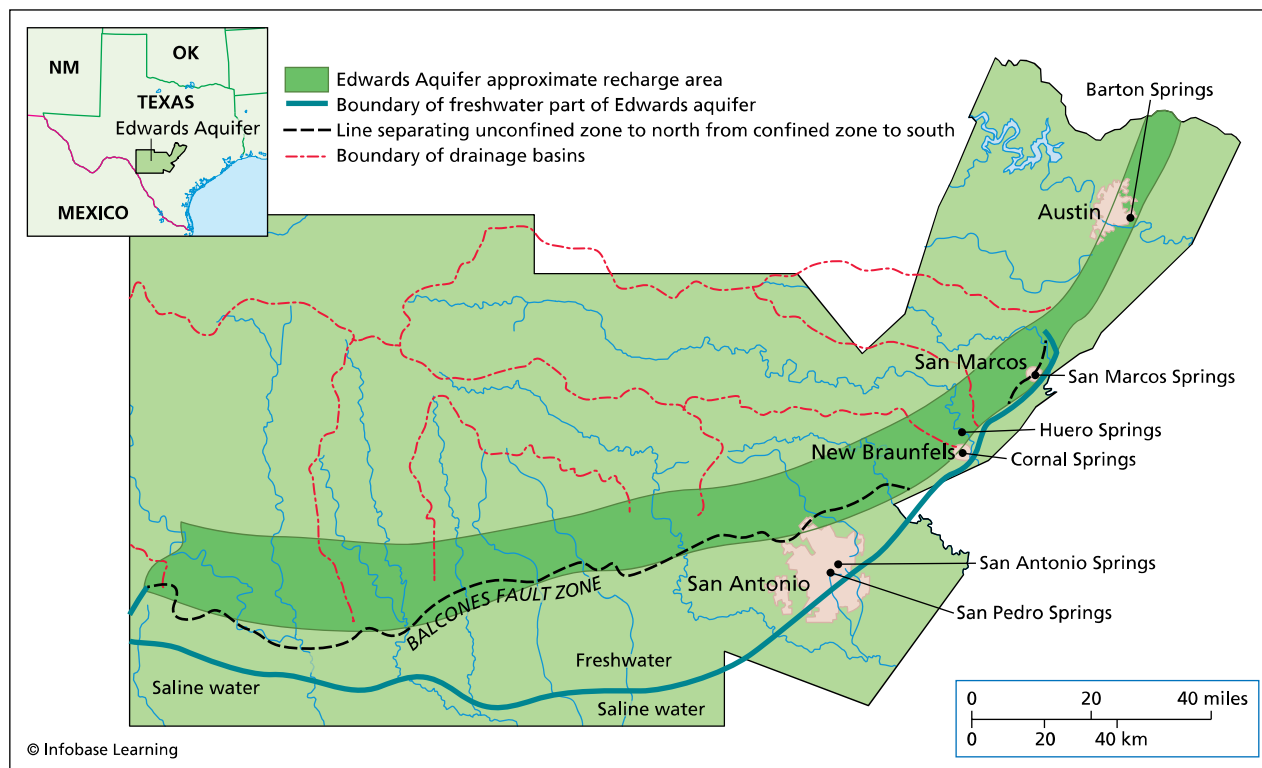
The city of San Antonio began using well water from the Edwards Aquifer for its water needs in 1891. The first well drilled sent a column of water shooting 25 feet (7.7 m) into the air. With such a valuable resource directly underfoot, the Edwards Aquifer quickly became the water supply of choice, and by 1896, there were 40 wells in the city, and the pressure was soon reduced to a trickle. In other areas of Texas, however, it still forms impressive springs in places such as the famous Barton Springs and is still artesian in several isolated spots. In 1991, one of the most productive wells in the world was drilled into Edwards Aquifer. This well yielded about 25,000 gallons (95,000 L) (approximately the size of a large backyard swimming pool) per minute without pumping. This rate is more than enough to supply the needs of most small to midsize towns and cities.



Artesian well in San Antonio, Texas (Peter Essick/Aurora Photos)

### ECOLOGY OF THE SPRINGS

It is the karst features of limestone aquifer that permit the extreme flow rates. Essentially, the water is flowing through caves, and, as such, certain organisms have adapted to live in them. Where the limestone breaches the surface, there is a very open



**Map showing the area served by groundwater from the Edwards Aquifer: Inset map shows the location of the Edwards Aquifer in Texas.**

interaction between surface water and groundwater, with disappearing streams in some areas and spring ponds in others. It is the spring areas of this aquifer that are homes to sensitive ecological communities that include several rare and endangered species, a few of which only occur in the Edwards Aquifer. The organisms emerge from the caves where there is no light, and many are blind or have no eyes at all. Several species include the Texas blind salamander, Helotes mold beetle, the Robber Baron harvestman, and the Robber Baron Cave spider, as well as the fountain darter and the San Marcos salamander. Many of these are endangered and on the verge of extinction.

### POLLUTION AND DEPLETION

As a result of the excessive demand of the burgeoning population in the area, the pressure of the urban/suburban sprawl into areas of aquifer recharge, and the efforts of environmentalists to preserve the water quality and ecology, the Edwards Aquifer has become one of the more prominent legislative battlegrounds in the United States. Recent droughts have threatened the ability of the aquifer to produce enough water to meet demand and raised the question of rationing. In areas of incursion of industry

and development, the quality of the water has suffered with contamination by pesticides, fertilizer, bacteria, and even solvents and heavy metals in the Austin and San Antonio areas. These upstream problems may cause even more severe problems in the downstream areas. The heavy usage can cause the saline water from the Bad Water Zone to be drawn northward into producing wells. The total dissolved solids in this water are about 1,000 parts per million (ppm), far below seawater but still not drinkable. This zone limits any possibility of drilling outside the current aquifer area without extensive desalination efforts. Such activities would also further draw down the already suffering Edwards Aquifer.

*See also* AQUIFER; KARST; PESTICIDES; SALTWATER INCURSION; WATER POLLUTION.

### FURTHER READING

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**Ekofisk oil field North Sea, Norway April 22, 1977 Water Pollution** Aided by new technologies developed during the cold war, by the 1960s, exploration for oil entered a new level of sophistication. Using such advances as seismic profiling and early data processing techniques, the age of the "wildcat," or the drilling for petroleum hydrocarbons in an area that had not been known for producing oil, was coming to a close. As a result, in the early 1960s, a major new source of oil and natural gas was discovered beneath the North Sea off the coast of Norway. The discovery was in a structure that subsided during the opening of the Atlantic Ocean, called a graben. About 65 million years ago, when the graben formed, it was flooded with sediment rich in organic debris. With time, the organic material in the sandstone and shale that had been buried in the graben was heated and pressurized to form oil and natural gas. These valuable hydrocarbons were trapped in chalk deposits overlying the graben. The oil and gas remained for tens of millions of years, more than one mile (2,900 m) below the seafloor beneath one of the stormiest oceans on the planet, until the late 1970s, when the Ekofisk oil field platforms were brought online and began pumping oil and gas into an undersea pipeline.

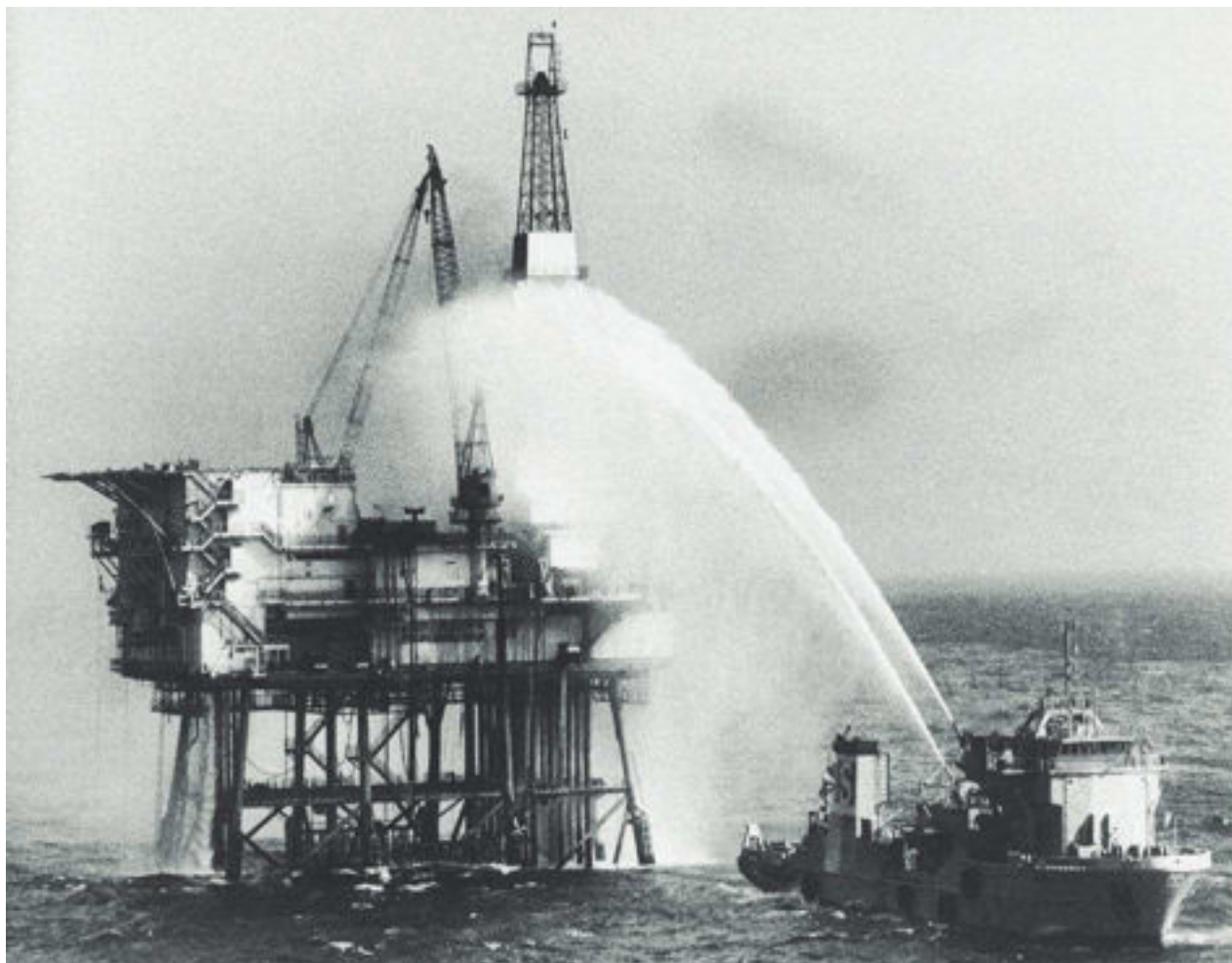
Thanks to the Ekofisk oil field, and the other giant North Sea Norwegian oil fields—Brent, Forties, Statfjord, Gullfaks, Heidrun, and Oseberg—Norway emerged as one of the most important non-Organization of Petroleum Exporting Countries (OPEC) (i.e., non-Middle Eastern) sources of oil. In 2002, Norway was the world's third largest net oil exporter and the second largest natural gas provider to Western Europe. Norway's economy is connected closely to its offshore oil and natural gas production, which is its largest source of hard cur-

rency, representing about 18 percent of Norway's gross domestic product. Under international law, Norway owns the continental shelf seabed off its coastline beneath which the oil and natural gas is present. It leases the rights to explore for oil to private companies and charges a royalty for every barrel of oil or cubic foot of gas produced. Although Norway's oil and natural gas are expensive to find and recover because of their great depth below a cold and windy ocean, the oil and natural gas in the North Sea, as well as Norway's political stability and closeness to European markets, allow Norway to enjoy one of the highest per capita income levels in the world.

## BACKGROUND

The Ekofisk oil field is some 200 miles (320 km) east of the Norwegian coastline, and recoverable quantities of oil were first discovered there in 1969. By 1971, Philips Petroleum (now ConocoPhillips) had begun production from a series of interconnected offshore oil platforms where more than 500 people lived and worked. This one-mile- (1.6-km-) long complex included the Hotel Platform, where crew slept, ate, watched the latest movies in a 115-seat theater, visited a chapel, and exercised. Oil and natural gas flowed under their own pressure up through the one-mile- (1.6-km-) deep drilled wells and into pipelines that carried them to processing and refining facilities in Norway or Denmark and, in some cases, the United Kingdom.

In the 1970s, oil prices rose steadily in response to an oil embargo placed on the United States and its Western allies for their support of the 1973 Israeli Yom Kippur War by the Organization of Arab Petroleum Exporting Countries (OAPEC), including Kuwait, Syria, Egypt, Libya, and Saudi Arabia. The embargo also served as a demonstration by both OAPEC and other oil-producing countries that they were in control of their domestic petroleum industries and the pricing of their crude oil. As the flow of oil from the Middle East decreased and as the price rose, the pressure for increased production from the Ekofisk and other North Sea platforms increased. Working around the clock, the men and women staffing the Ekofisk platforms would increase production from 13.7 million cubic feet (0.4 million m<sup>3</sup>) of oil and gas in 1971 to almost 550 million cubic feet (16 million m<sup>3</sup>) by 1977. As more wells were drilled and additional platforms added to handle this increased production, work and safety procedures on the normally very tightly regulated and controlled platforms began to slip.



Norwegian fireboat Seaway Falcon pours water on oil platform “Bravo” in the North Sea, April 24, 1977. (© UPI/CORBIS)

### THE ACCIDENT AND SPILL

On April 22, 1977, one of the 15 production wells on the “Bravo” platform (Bravo 14) at the Ekofisk field was taken off-line for routine maintenance. Prior to taking a well out of service, the operators make sure that its blowout preventer, or BOP, is in place. Oil and natural gas present more than one mile (1.6 km) below the seabed are under tremendous pressure, and to stop their uncontrolled release, called a blowout, special valves or devices are used to seal off or cap the flow of oil or gas in an emergency. On the Bravo platform, each well had two BOPs, one 164 feet (50 m) below the bottom of the seafloor and another at the wellhead, the part of the piping that is connected to the floor of the platform. As the crew performed their “well workover” duties, basically the removal and replacement of gauges and tubing that line the inside of the well, a heavy mud was being pumped into the well to help keep the oil and gas inside the formation. The lower BOP was open to allow the drilling mud to pass through it, and

the surface BOP had been disassembled for repairs. As new gauges were being installed, mud started to bubble out of the well, and, despite the frenzied efforts of the crew to reattach the topside BOP, a blowout occurred and oil and natural gas began to shoot more than 150 feet (45.7 m) into the air at about 175 tons per hour (158,757 kg/h). Fearing a fire or explosion, the 112-person crew quickly abandoned the platform and began emergency response procedures.

Despite the gale-force winds and 15-foot (4.6-m) seas, a firefighting boat stationed at the platform was deployed and began to spray water on the gushing tower of oil to cool and help disperse it and to prevent the buildup of natural gas. Chemical dispersants—whose use was prohibited under the operating agreement between Phillips and Norway—were sprayed around the platform to try to break up the rapidly forming slick.

Within a few hours of the release, platform operators knew they did not have the knowledge or

capability to cap or, “kill,” the out-of-control Bravo 14 well. They turned to the world’s best oil-well fire and blowout control expert, Paul “Red” Adair. Growing up in Texas, Red Adair had been around oil rigs all of his life. During World War II, he served in a bomb disposal unit. Returning to civilian activities, he put his new-found knowledge of explosives to profitable use, devising new ways to extinguish oil-well fires by using explosives to snuff or blow them out. Often after the fire was out, the job of sealing the well and stopping the uncontrolled flow of oil arose. Together with his longtime friend and business associate Asger “Boots” Hanson, Red Adair had helped control such notable fires and blowouts as the 1962 oil-well fire in the Sahara, nicknamed “the devil’s cigarette lighter,” because of flames extending more than 400 feet (121.9 m) from the ground, as well as the Ixtoc I blowout in the Gulf of Mexico in June 1979 and the Piper Alpha fire and spill in July 1988. Perhaps his most notable achievement occurred at the age of 75, when he and his company helped extinguish more than 100 oil-well fires started by Iraqi troops retreating from Kuwait during the 1991 Gulf War.

Boots Hanson arrived within 12 hours of the blowout and started to assemble an all-volunteer team to board the Bravo platform and seal the well. Working conditions were far from ideal: The seas and winds were still very stormy, the noise near the wellhead tremendous, and those working around the well were surrounded by very flammable and explosive levels of oil and natural gas. Joined a few days later by Red Adair, the team, which included members of the company that drilled the well and Philips engineers who operated it, took eight days and five attempts to complete the dangerous work of reinstalling and successfully closing the hardened rubber disks in the topside BOP that would seal the well and shut down the uncontrolled flow of oil. With only a few minor injuries and no loss of life, the Bravo 14 blowout was finally under control. Oil production from the Ekofisk platform resumed four hours later.

### THE CLEANUP

Although the rough seas and strong winds hampered well-closure efforts, they aided in minimizing ecological impacts from the blowout. The type of oil released was fairly low-density liquid, or “light” petroleum, which was pushed out of the wellhead at very high pressures and at temperature close to its boiling point. Several studies estimated that about 50 percent of the oil evaporated before it had contact with the ocean, while the remainder formed a discontinuous slick 45 miles (72.4 km) long by 30 miles (48.3 km) wide,

but only a few tenths of inches thick. The blowout is thought to have released a total of 30,000–60,000 tons (7.5 million–15 million gallons, or 28.4 million–56.8 million L) of oil over an eight-day period. Although mechanical skimmers were in use constantly almost immediately after the blowout occurred, the rough seas and lack of experienced operators limited their effectiveness, and they collected only about 800 tons (200,000 gallons, or 757,000 L) of oil, a very small fraction of that which was released. Wave and wind action, as well as the water spray from the fire vessel that was deluging the Bravo platform, served to mix and emulsify the oil, causing it either to dissolve in the sea or to congeal and sink to the bottom. These same winds also blew the slick away from the Norwegian coastline and out into the open ocean. By May 9, 18 days after the blowout, no visible evidence of an oil slick could be found.

### THE AFTERMATH

Ecological impacts from the blowout were not apparent. Later studies found no damage to fish, larvae, seabirds, or other marine life. Evidence for this and other releases tends to confirm the general oil industry consensus that the most severe environmental effects are those that occur when oil is released close to land, where it can wash onto beaches, or into sensitive habitats such as estuaries or nesting/spawning grounds. Ocean oil spills are readily processed by the natural dispersion, attenuation, and biodegradation mechanisms that operate in the vastness of the open seas.

An investigation of the spill by the Norwegian government, including the police, who looked at possibly filing criminal negligence charges against the well operators, found that workers had failed to follow required procedures and did not notice several unusual indications of potential wellhead problems. Mud had begun leaking out of valves and tubing at the top of the well, and the topside BOP had been disassembled and was lying in two pieces on different levels of the platform. When the crew quickly tried to reattach it to the wellhead, they installed it upside down. The deeper, down-hole BOP had not been locked into place correctly, and it was later found lying relatively intact on the platform, blown out of the well from more than 100 feet (30.5 m) below the seafloor. The financial losses associated with the Bravo blowout totaled approximately \$200 million, with more than half (about 65 percent) lost royalties and taxes that should have gone to the people of Norway.

North Sea oil production peaked in 1999 and has been declining at an annual rate of about 3



percent per year. Ekofisk is expected to continue to produce economic quantities of oil until 2050. Even though improved operational and training procedures have prevented other major blowouts at Ekofisk, the oil field recently faced the new problem of subsidence. As the oil was removed from within the fractures and breaks in the rock, they began to recrystallize and seal, with a resulting loss of overall volume. As more oil was removed, the seabed upon which the oil platforms rested began to sink, in some places by almost 10 feet (3.1 m). This subsidence obviously represented a major threat to the structural integrity of the oil platforms and could not be allowed to continue. The solution developed to address this problem included the reinjection of water into the wells as the oil was drawn out. This not only reduced the subsidence but also had the added benefit of increasing oil recovery rates as the injected water helped flush oil from the fractures and joints of the rock.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS; SANTA BARBARA OIL SPILL; TORREY CANYON OIL SPILL.

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**Endicott solvent contamination**  
**Endicott, New York 1979-present Water Pollution** The Village of Endicott, a subdivision of the town of Union, New York, about 185 miles (298 km) northwest of New York City, proudly proclaimed itself as the "Birthplace of IBM." In 1888, Herman Hollerith, a statistician, founded the Tabulating Machine Company in Endicott, attracted to the village by its machine shops, a reliable supply of clean water from the nearby Susquehanna River, and the

industrial infrastructure in the area. Once established in a small two-story brick building, Hollerith won his first contract with the U.S. Census Bureau and used a machine of his own creation to process population and demographic information from the 1900 census on small cards with tiny holes punched through them.

By 1911, the company had merged with two others to form the Computer Tabulating and Recording Corporation (CT&R) and was processing freight bills for the railroads, claim information for insurance companies, and personnel data for the military. Never selling its equipment, CT&R began to build and lease card-punch and card-reading machines to customers. In 1924, just a few years before its founder's death, the company was renamed International Business Machines Corporation, or IBM. Today, with more than 300,000 employees, IBM is the world's second largest computer company, manufacturing and selling computer hardware, software, and consulting services that include everything from large mainframe systems to research on nanotechnology.

#### THE POLLUTION INCIDENT

As IBM grew, so did its need for local industrial manufacturing space. By the late 1970s, it operated on 40 acres (57 ha) in 30 separate and interconnected buildings within Endicott and was one of the area's major employers. IBM also ran other production facilities in nearby Fishkill and Beacon, New York. The company's manufacturing activities involved the use of a wide variety of industrial solvents, which were not always carefully handled or managed. In 1979, an employee accidentally released 4,000 gallons (15,000 L) of 1,1,1-trichloroethylene (TCA). IBM moved quickly to clean up the spill, but subsequent soil and groundwater investigations found a large plume of contamination that indicated apparent ongoing chemical releases over a long period. In addition to 1,1,1-TCA, environmental hydrogeologists retained by IBM and the New York Department of Environmental Conservation (DEC) found trichloroethene (TCE), tetrachloroethene (PCE), methylene chloride, Freon, benzene, and other solvents in groundwater not only beneath the IBM Endicott property but also underlying nearby residential and commercial areas.

#### THE CLEANUP

To address the groundwater contamination, IBM instituted a series of corrective measures as part of its Resource Conservation and Recovery Act





IBM headquarters in Endicott, New York, ca. 1937 (@ Lake County Museum/CORBIS)

(RCRA) hazardous waste permit. Over the next 25 years, IBM installed and operated an extensive groundwater recovery program to capture and treat the contamination that had been released from its North Street facility.

When groundwater is withdrawn from an aquifer, or water-bearing zone, by a pump installed in a well, it causes a “cone of depression” in the water table whose shape is dependent on such factors as pumping rate, or the amount of groundwater being withdrawn over time; the amount of water the subsurface sediments hold; and the rate at which new groundwater can move through the subsurface to replace the groundwater that has been pumped out. When viewed from the surface, the cone of depression extends outward from the well to form a roughly circular zone, called an area of influence. When wells are aligned in a pattern such that their cones of depression overlap, they create an obstruction or barricade through which groundwater cannot move. This remedial approach is called pump and treat, a system of wells aligned to form a subsurface hydraulic barrier so as to collect contaminated groundwater for subsequent treatment and prevent its migration to uncontaminated areas. Treated water is discharged to the local storm or sanitary sewer or sometimes is pumped back into the ground to try to flush remaining contaminants out of the soil.

By 2005, IBM had drilled and sampled more than 220 monitoring wells and was recovering water from 17 extraction, or pumping, wells at its plant site and at various locations throughout the village of Endicott. This water was treated by passing it through an air stripper to force the volatile organic contaminants out of solution and then through a granulated activated carbon (GAC) recovery unit.

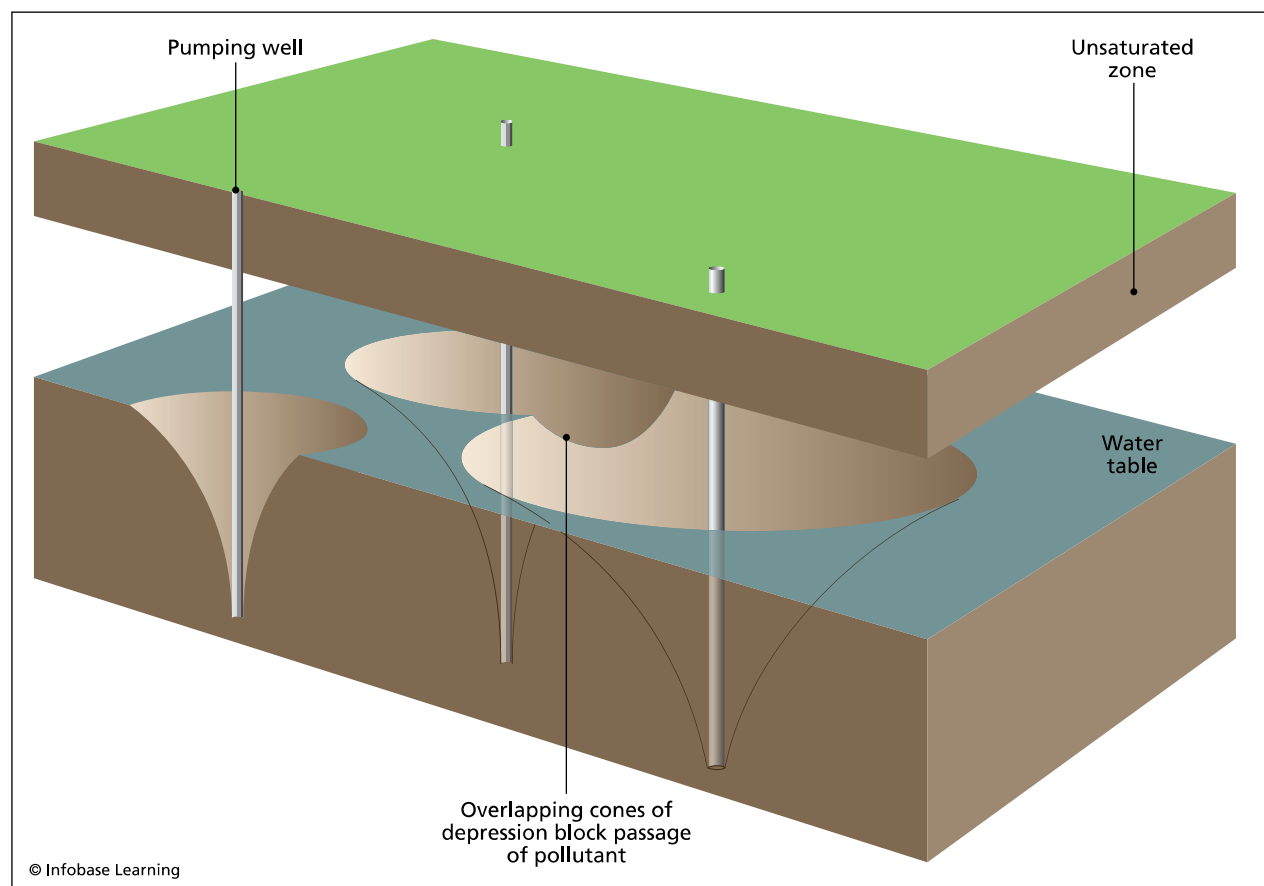
The local hydrogeology complicated IBM’s remedial efforts. Five distinct geologic units underlie the village, and groundwater is present in at least two aquifer systems. At the surface, there are a layer of unconsolidated alluvium of silt, sand, and gravel washed up onto the site as the Susquehanna River carved out the valley, as well as fill composed of various types of soil and debris placed throughout the village to raise sections of it up to a usable grade. Groundwater is present in this layer and only a few feet below the surface. Underlying the alluvium and fill is an extensive layer of lake-deposited silt intermixed with glacially derived, silty fine sand. This layer is relatively impermeable and acts as an aquitard, or a type of geologic unit that tends to slow the vertical movement of contaminants that have been released into the alluvium and fill. Below the silt and silty sand is a layer of coarse-grained sand and gravel, formed and deposited by glacial meltwater. These deposits together with the deeper shale bed-

rock compose the main aquifer in the area and serve as the primary source of drinking water for Endicott and Union. Commonly present on top of the shale bedrock and underneath the glacial outwash deposits is an intermediate layer of dense, consolidated glacial till made up of clay, silt, sand, and gravel. All five of these units vary in thickness and may not even be present, depending upon how the river and glaciers moved across the area.

The majority of the IBM-operated extraction or pumping wells have been drawing water from the alluvium and fill, for it is in this geologic layer that most of the chemical releases occurred. Some contamination has been detected in the deeper aquifer, however, and IBM has installed and is operating groundwater recovery wells that also tap this water-bearing zone. Additionally, IBM has paid for the installation of a special water treatment system on a municipal well; this well extracts groundwater from the outwash and bedrock aquifers.

On average, about 6,000 pounds (2,700 kg) of volatile organic chemicals are recovered every year

from the more than 150 million gallons (568 million L) of groundwater pumped from beneath the village and IBM plant. This water is sampled and then discharged to local storm sewers in accordance with a variety of New York State discharge permits held by IBM. As might be expected, the highest levels of subsurface contamination are present near the IBM plant, but the TCE and other solvents making up the contaminant plume have moved with local groundwater flow patterns and migrated southward off the IBM property and toward the Susquehanna River. Although pollutants have been detected in groundwater samples from both the shallow and deep water bearing zones, it is clearly the near-surface aquifer that has been most affected. The village's water supply system has been adequately protected by the actions taken by IBM and NYSDEC. The volatile organic compound (VOC) pollutants in the groundwater present the health risk of vapor intrusion into basements of those homes and buildings it has migrated beneath.



**Overlapping cones of depression from pumping wells effectively form a barrier against the migration of light non-aqueous phase liquid (LNAPL) pollutants in an area. LNAPLs float on top of the water table and are drawn off in the well. The water can then be treated in an ex situ remediation system.**

### A NEW THREAT, VAPOR INTRUSION

As the dissolved chemicals in the groundwater move through the subsurface, they encounter features and conditions that reduce their ability to remain in solution. The types of chemicals released at the IBM site readily evaporate. VOCs such as benzene or toluene, which are the principal constituents of gasoline, evaporate readily. When the contaminant is dissolved in and moving with groundwater and flows underneath buildings, VOC vapors may push up through the soil and enter the overlying structures, following outside pipe ways, or seeping through cracks in building foundations or floor slabs. This process, called vapor intrusion, may result in the accumulation of unhealthy levels of VOCs inside buildings and expose building occupants to adverse health effects through the inhalation of those compounds.

The potential health impacts from soil vapor intrusion first attracted widespread attention in the environmental and regulatory community in the late 1990s and early 2000s as a result of a study conducted in Redfield, Colorado. Although the magnitude of the public health issues surrounding this phenomenon is still being quantified, USEPA, NYSDOH, NYSDEC and IBM took aggressive action to assess and remedy places at Endicott where it may have occurred.

In 2001, a series of studies began to determine whether VOC vapors had migrated into homes and businesses above the contaminant plume and, if they had, how much was present. In study areas to the southwest (downgradient) of the IBM property, PCE and TCE were found in indoor air at concentrations between 0.1 to 140 mcg/m<sup>3</sup>. Soil gas samples taken from below building floor slabs and in areas adjacent to homes contained much higher TCE values, greater than 10,000 mcg/m<sup>3</sup>, and PCE, another organic solvent, but one not used by IBM, was found in indoor air samples at above 20 mcg/m<sup>3</sup>. NYSDOH has established exposure guidelines for PCE of 100 mcg/m<sup>3</sup> and for TCE of 5 mcg/m<sup>3</sup>. Although the possibility of serious health effects related to the concentrations of PCE and TCE found in air samples from the tested homes is low, the presence of much higher values in soil gas samples made it prudent to conduct mitigative actions.

PCE, which has not been tied to releases from IBM, is present in some types of spot removers and is used in dry cleaning. Other types of businesses also use these chemicals including auto body repair shops, printers, and metalworking facilities. The source of the PCE found in soil gas at Endicott has not been determined, but NYSDEC suspects that

it may have originated from several dry cleaners in the area.

Soil gas venting systems consist of a series of perforated pipes driven or drilled into the soil adjacent to a building, or even through the floor slab of a basement. A flexible hose or rigid plastic tube is attached to the end of each pipe and connected to a vacuum pump that continually draws air from the subsurface and out a central stack or vent usually installed on the roof, where it is safely dissipated into the atmosphere. Diverting the soil gas into the vapor extraction system greatly reduces or minimizes the likelihood that PCE or TCE will enter the building. These types of systems were installed in almost 500 Endicott businesses and homes.

Both NYSDOH and IBM have repeatedly stated that concentrations of TCE found in indoor air contaminants are well below those that cause negative health impacts; however, some residents are concerned that illnesses and cancers are related to them. Many are considering legal action against IBM. Two studies done in 1986 and 1995 by NYSDOH, however, concluded that there has been no increase or decrease in cancer occurrence since the contamination was first reported. Studies about the possible effects of TCE in indoor air on residents' health are ongoing.

IBM has offered to compensate property owners who have had a ventilation system installed with a one-time payment of \$10,000, or 8 percent of the full market value of their property, whichever amount is larger. If the owner accepts the money, however, he or she cannot file a claim against IBM for property damage in the future. Property owners would still be able to pursue personal injury or other claims associated with the contamination.

*See also* AQUIFER; BENZENE; CHLORINATED SOLVENTS; IN SITU GROUNDWATER REMEDIATION; PCE; SUPERFUND SITES; TCA; TCE; TOLUENE; VOLATILE ORGANIC COMPOUND.

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**endosulfan** Even though endosulfan is present in only 17 of the first 1,177 U.S. Environmental Protection Agency (EPA)–designated Superfund sites, it is still rated 54th of the 275 compounds on the 2007 CERCLA Priority List of Hazardous Substances, and endosulfan sulfate, which is a breakdown product of endosulfan, is rated 55th. The reason for the high rating is that endosulfan is a highly toxic restricted use pesticide (RUP) as of 1991 that is considered to be in the EPA toxicity class Ib (highly hazardous). It may not be present in many hazardous landfills, but because it is so widely distributed and so toxic, it is regarded as an extreme environmental threat. It was even involved in a major poisoning incident in Kerala, India, in 2001. Endosulfan is also known as Afidan, Benzoepin, Beosit, Cyclodan, Devisulfan, Endocel, Endocide, Endosol, FMC 5462, Hexasulfan, Hildan, Hoe 2671, Insectophene, Malix, Phaser, Thiodan, Thimul, Thifor, and Thionex, among others (94 products in total).

### PROPERTIES, USES, AND PRODUCTION

Endosulfan is a chlorinated hydrocarbon of the cyclodiene subgroup that is used as an insecticide and an acaricide. Endosulfan occurs as colorless to yellow-tan sugary crystals and is typically a mix of two forms, the alpha- and beta-isomers. It is commercially available as an emulsifiable concentrate, wettable powder, ultra-low-volume (ULV) liquid, and smoke tablets. It is primarily applied to crops such as tea, coffee, cotton, oilseed, fruits, and vegetables (squash, eggplant, cantaloupe, sweet potatoes, broccoli, lettuce, pears, pumpkins, tomatoes, melons, apples, strawberries, grapes, blueberries, and many others), as well as to rice, cereals, maize, sorghum and other grains and to Christmas trees and ornamental shrubs, trees, and vines. It has also been used as a wood preservative. Endosulfan was registered as a pesticide in the United States in 1954. The annual domestic use of endosulfan is estimated at 1.38–2.2 million pounds (627,272–1 million kg)

of active ingredient, but it is always used in a diluted form of 9–50 percent.

### ENVIRONMENTAL RELEASE AND FATE

Endosulfan is primarily released in agricultural applications as a nonpoint source pollutant and far less often as a point source pollutant from improper handling or spills and leaks during manufacture, transport, or storage. It is primarily released into the soil, where much of it evaporates and the rest enters and adheres to clay and organic particles. Endosulfan is moderately persistent in soils, with an average removal half-life of 50 days, although it is reported that the half-life for the alpha-isomer is 35 days and that the beta-isomer is 150 days. It has been shown to persist longer under acidic conditions. In sandy loam soil, it has been shown to have a removal half-life up to 800 days. Endosulfan breaks down to endosulfan sulfate, which is even more persistent and still toxic. In one study, after 11 weeks, 90 percent of the residue remained. Breakdown is primarily through biodegradation, though minor chemical reactions also contribute. Some endosulfan leaches into the groundwater and has been found in wells in California, but this occurrence is rare. It is more commonly washed into surface waters from runoff over agricultural fields. It does not dissolve well in water so is mainly carried along attached to particles until it settles into the bottom sediments and persists similarly to the way it persists in soil. The dissolved endosulfan either evaporates or breaks down relatively quickly, depending upon conditions (one day to two months). Strongly alkaline conditions promote faster degradation than neutral or acidic. Endosulfan can travel long distances in air before settling to the ground or breaking down through photochemical reactions.

Endosulfan is highly toxic to fish, birds, bees, aquatic organisms, and many insects, although not to some beneficial insects such as parasitic wasps and ladybugs. It has had 91 poisoning incidents reported on the EPA Ecological Incident Information System (EIIS), which accounts for 62 percent of all incidents since 1971. Endosulfan can bioconcentrate significantly in some organisms such as mussels, where it accumulates up to 600 times the ambient water levels.

### HEALTH EFFECTS FROM EXPOSURE

Endosulfan has been shown to produce numerous serious health effects through both acute and chronic exposure. Acute exposure has produced adverse effects on the central nervous system and gastrointestinal



tract including hyperactivity, hypersensitivity to light and noise, muscle tremors, salivation, loss of coordination, gagging, vomiting, diarrhea, agitation, possible temporary blindness, periodic and continuous convulsions, loss of consciousness, and death at a high enough dose. Long-term chronic exposure produces damage to the liver, kidneys, blood chemistry, parathyroid gland, and immune system. It has also been shown to damage the reproductive organs and cause skeletal deformities in fetuses. Endosulfan does not appear to be carcinogenic, but it is so toxic that the mortality rate of the laboratory animals was very high during experiments. More tests may be needed to verify its potential as a carcinogen. It has been shown to be mutagenic to cells in laboratory tests, a finding that may suggest the ability to induce cancer.

### REGULATIONS ON HUMAN EXPOSURE

As a result of the extreme toxicity, several federal agencies have regulated human exposure to endosulfan. Besides the restrictions imposed by the RUP status, the EPA recommends a limit of 74 parts per billion (ppb) of endosulfan in water from lakes and rivers and 0.1–2 parts per million (ppm) on the surfaces of agricultural products. They are currently considering additional restrictions. The Occupational Safety and Health Administration (OSHA) has set a permissible exposure limit (PEL) of 0.1 milligram of endosulfan per cubic meter of workplace air over an eight-hour-day, 40-hour workweek. Endosulfan has been banned in at least 80 countries and severely restricted in 12 others.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

### FURTHER READING

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**endrin** There are numerous toxic pollutants. The only people poisoned by the vast majority of them are careless or uninformed industry workers or those who wish to take their own lives. This is not the case with the pesticide endrin, which is responsible for the poisoning of several groups of people around the world. Perhaps the most famous incident is the 1967 death of 26 Saudi Arabians and hospitalization of 874 others that resulted from endrin residues in bread. It was for this serious public health threat that the Environmental Protection Agency (EPA) severely restricted its use in 1979 and finally banned it altogether in 1991. Even after all of this time, endrin is still rated number 41 on the 2007 CERCLA Priority List of Hazardous Substances, which includes 275 entries. It has been identified in 120 of the first 1,428 U.S. Environmental Protection Agency (EPA)–designated Superfund sites, and its metabolite endrin epoxide has been identified in 37 Superfund sites (National Priorities List). The pesticide endrin is also known as Nendrin, EN 57, Endrex, Endricol, Hexadrin, Mendrin, Oktanex, and Compound 269.

### PROPERTIES, USE, AND PRODUCTION

Endrin is an aliphatic organochloride (organic carbon and chlorine atoms bonded together) and a cyclodiene pesticide (carbon bonded to a chlorinated methylene group) that does not occur naturally. It is closely related both chemically and structurally to aldrin and dieldrin. Endrin is a sugary solid that is colorless, white, or tan and has a faint chemical odor. It was primarily used as an insecticide but also in control of rodents and birds. As an insecticide, about 80 percent was used on cotton with additional applications to other field crops such as maize, sugarcane, rice, wheat and cereals, and tobacco in Australia. It was also used on ornamental shrubs and trees, and sugar beets, as seed treatment, and as a cutworm treatment for corn and potatoes. Endrin has been used to control rodents (mainly mice and voles) in orchards, unwanted bird species

on buildings and other structures, and grasshoppers in noncroplands. Endrin was first used in the United States in 1951. Production peaked in 1961 at 10 million pounds (4.5 million kg), but after news of the poisoning incidents emerged, it decreased to 1 million pounds (454,545 kg) by 1971. Production declined to 100,000 pounds (45,545 kg) in 1980 immediately after the first restriction in 1979 and was completely terminated even before the second restriction in 1991.

### ENVIRONMENTAL RELEASE AND FATE

As with most other pesticides, almost all endrin that was produced was released to the environment as a nonpoint source pollutant. The only point source pollution results from improper disposal and leaks and spills from production, transport, and storage. Endrin is almost exclusively released to soil and very little evaporates. Instead, it adheres tightly to organic and clay material within the soil and remains fixed for potentially long periods. One study found that after 14 years of degradation, 41 percent of the original endrin remained in the soil. This means that endrin applied many years ago may still be a threat to those who may have contact with it today. Another study, however, found small quantities of endrin in groundwater, an indication that under certain conditions, it may not be as tightly fixed in the environment and leach deeper into the soil. As recently as 1996, endrin was found in significant quantities in soils in California, Alabama, Georgia, Illinois, Arkansas, Louisiana, New York, New Jersey, Nebraska, North Carolina, and Florida. Endrin slowly degrades through chemical reactions and microbial activity under anaerobic conditions. Runoff over agricultural areas carries it into surface water. Once there, endrin attaches itself to particulate matter and settles into the bottom sediments, where it is also quite persistent. Endrin has entered the atmosphere where it has been sprayed but primarily attaches itself to dust and other particulates and returns to the surface by fallout or washout during precipitation events.

Endrin is devastating to the ecology of an area. It is highly toxic to fish, birds, small animals, aquatic invertebrates, bees, and other insects. There is high bioconcentration of endrin in fish and snails, with factors of 1,335–10,000 and up to 49,000 times ambient levels, respectively. Endrin is also taken up by roots and distributed throughout the leaves of many plants, making it an effective pesticide. In studies on tobacco plants, the rate of uptake was 32–47 percent. Cotton plants were found to distribute the endrin to their leaves, where 60 to 80 percent

evaporated within six to 18 weeks. This indicates that endrin residues may persist for a long time.

### HEALTH EFFECTS FROM EXPOSURE

Endrin is a strong poison that produces dangerous health effects. With acute exposure, it can irritate the skin and eyes and even damage vision. It causes nausea, vomiting, diarrhea, loss of appetite, profuse sweating, muscle weakness, headaches, confusion, dizziness, and muscle tremors. At high dosage, it causes periodic to continuous seizures, unconsciousness, coma, and death relatively quickly. It may take many weeks for the acute symptoms to subside. Long-term, chronic exposure of laboratory animals to endrin produces irritability, depression, anxiety, numbness, weakness in the hands and feet, and liver damage at low doses and damage to the brain, liver, kidneys, and adrenal glands at high doses. There are no definitive studies linking endrin exposure to increased incidence of cancer, and it is not currently considered to be a carcinogen.

### REGULATION OF HUMAN EXPOSURE

Besides the bans, public and worker exposure to endrin is regulated by several federal agencies. The EPA limits endrin in drinking water to a maximum of two parts per billion (ppb) under the Safe Drinking Water Act. They recommend a maximal exposure of 20 ppb for any 10-day period for adults and one-day period for children, but for any longer periods it should not exceed 3 ppb for children or 10 ppb for adults. The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) of 0.1 milligram of endrin per cubic meter of workplace air over an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) has set their recommended exposure limit (REL) as the same as OSHA's but over a 10-hour day. They have further set their immediately dangerous to life and health (IDLH) limit to 2 milligrams of endrin per cubic meter of workplace air, which is very low. Endrin has been banned in only seven countries including the United States. This means that imported food from many countries may still contain endrin residues.

*See also* ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SOIL POLLUTION; SUPERFUND SITES; WATER POLLUTION.

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**Ensign Bickford Simsbury, Connecticut 1997 Soil Pollution** Since 1836, Ensign Bickford Company of Simsbury, Connecticut, which is now owned by Dyno Nobel, has been developing and testing explosive products at its 350-acre (142-ha) facility, 15 miles (24 km) northwest of Hartford. The property is divided into two sections: a 200-acre (81-ha) western parcel, which is heavily wooded and contains numerous bunkers used for the storage of raw materials and finished goods, along with several process buildings; and a 150-acre (61-ha) eastern operational area where the majority of manufacturing and waste management activities have taken place.

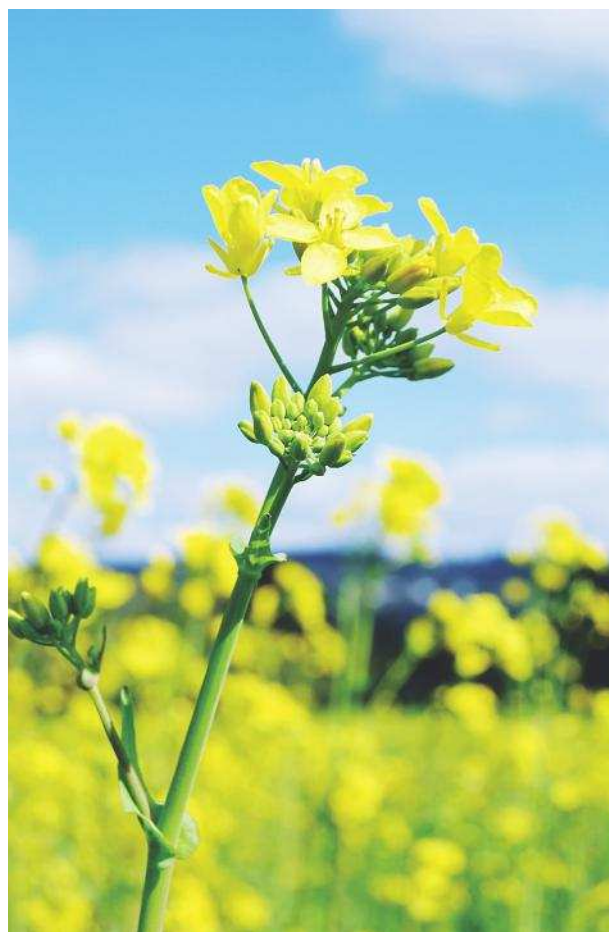
### CONTAMINATION OF THE SITE

During manufacturing, blasting agents, pyrotechnics, primers, and boosters were developed and tested in a three-acre area of the eastern parcel called the Open Burn/Open Detonation (OB/OD) area. This type of open-air testing was standard industry practice, but is no longer done as more sophisticated computer modeling and laboratory testing techniques have replaced "fire-in-the-hole" approaches. As have many industrial activities, open-air detonation of explosives left an environmental legacy that had to be addressed. Soil at the OB/OD area is a silty loam with a pH in the range of 6.5–7.5. The water table is relatively shallow (two to four feet, or 0.6 to 1.2 m, below surface), and site drainage is poor, with portions of the property remaining saturated

throughout most of the growing season from April to October. In fact, most of the OB/OD area is within the 100-year floodplain of the nearby Farmington River. Inside the OB/OD area, the soil contains lead with an average concentration of 635 mg/kg to more than 4,000 mg/kg in a few places. Most regulatory agencies consider lead concentrations in soil safe for residential uses if they are at 100 mg/kg or less. Working proactively with the U.S. Environmental Protection Agency (EPA) and Connecticut Department of Environmental Protection (CTDEP), Ensign Bickford funded a phytoremediation project on a 2.4-acre (1-ha) tract of the OB/OD area to address this soil contamination.

### REMEDICATION OF THE SITE

Plants are very adept at extracting water from soil. The remedial practice of phytoremediation, also known as phytoaccumulation or phytoabsorption, takes advantage of this capability and occurs when



Mustard flower (*Brassica juncea*), often used in phytoremediation, in blossom (Joellen L Armstrong; used under license from Shutterstock, Inc.)



soluble contaminants, including metals and radionuclides, are taken up by the roots and concentrated in the aboveground portion of the plant. The contaminants are not altered or degraded, merely relocated to the leaf or stem. The plant then is harvested and disposed of in an appropriate manner, usually by incineration, or the metals can be chemically extracted from the plant for recycling.

Although heavy metals are generally phytotoxic, some plants, known as hyperaccumulators, have developed on metal-rich soils and can tolerate concentrations 100–1,000 times higher than less resistant types can. Hyperaccumulators generally are considered to be plants that have a ratio greater than 1 for concentrations of metals in the roots compared to the leaf and stem. Phytoextraction occurs in the upper portion of the root zone, which in most plants is the top two feet (0.7 m) or so of the soil column, which is relatively shallow. This may be a limiting factor in the application of phytoextraction as a broadly used remedial technique, although deep tilling has been effective in moving soil from six to eight feet (2 to 2.7 m) below the surface to within two feet (0.7 m) of grade, well within the root zone of most plants.

Another factor limiting the use of phytoextraction is the sorption, or attachment, of metals onto soil particles. Clay particles in soil are negatively charged, whereas most inorganic metal ions are positively charged. This causes the inorganic metals to sorb, or attach themselves, to the surface of the clay particles. To keep the metals available to the plants, a chelating agent can be added to the soil. A chelator is an organic compound that bonds with and removes free metal ions from solutions. Ethylenediaminetetraacetic acid (EDTA) is a synthetic amino acid that is particularly effective at this. EDTA, which is most commonly used in the treatment of lead poisoning, can be mixed with the soil to help liberate the metal from the clay and allow it to be taken up by the plant. Its use must be carefully monitored, so that the metals placed into solution are not leached into the groundwater before they can be drawn up by the root system.

At Ensign Bickford, the OB/OD area was divided into five zones based upon contamination. The Ensign Bickford remedial engineers first tilled nitrogen, phosphorus, and potassium fertilizers into the lead-contaminated soil. To raise the pH, dolomite lime ( $\text{MgCaCO}_3$ ) also was added. The areas were irrigated by an overhead spray system that additionally was used to provide supplemental foliar fertilizer that is absorbed through the leaf of the plant, not the roots.

During a single six-month growing season, an aggressive cultivation program was carried out. Indian mustard (*Brassica juncea*) was first planted then harvested, followed by sunflowers (*Helianthus annuus*), and then, after harvesting, there was

another planting of Indian mustard. Results were very encouraging. Total lead concentrations in soil decreased in four of the five test plots by about 25 percent, from 635 to 478 mg/kg, and no soil samples contained concentrations of lead above 4,000 mg/kg. Sunflower and Indian mustard plants successfully extracted lead at similar rates, about 1,000 mg/kg on a dry weight basis. Harvested plants were incinerated at an authorized disposal facility. Because of a high water table in Area 5, plant growth was not as optimal, and phytoextraction was less successful. Digging up and disposing of impacted soil off-site addressed contamination in this area.

As a result of this phytoextraction project, as well as other remedial efforts undertaken by Ensign Bickford, EPA and CTDEP have found that contaminated groundwater remains within the facility's property boundaries, is being effectively monitored, and does not pose an uncontrolled threat to nearby groundwater users.

See also BIOREMEDIATION; INORGANIC POLLUTANTS; IN SITU GROUNDWATER REMEDIATION; LEAD; PHOSPHORUS; SOIL POLLUTION.

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**Environmental Protection Agency (EPA), U.S.** Between the mid-1700s and early 1800s the basic tenets of Western Europe in regard to labor-driven agriculture, animal- or wind-based transportation, and individual or small guild-organized production processes began to change. The Industrial Revolution, for example, introduced coal-powered machines that required large, centralized factories and were able to mass-produce high-quality, inexpensive products. Steam-driven locomotives and ships now could move enormous quantities of



goods and people rapidly and almost independently of weather. By the late 1800s, the internal combustion engine would be able to drive machines that quickly and efficiently plow fields, plant seeds, and harvest crops.

As these technological advances overtook Europe and North America, people began to view their relationship with the world in a different way. Survival was no longer a struggle based on dominating nature, and, as the waste and unusable by-products of these modern technologies began to accumulate in the air and water, a new sense of responsibility or stewardship toward the Earth and its resources began slowly to form among a small dispersed group of citizens. First articulated by Ralph Waldo Emerson, Henry David Thoreau, and other American writers and philosophers, transcendentalism (as it came to be known) was based in part on establishing a close, intimate connection with the natural world. Although never a significant political force in the United States, transcendentalism provided the basis for the conservation movement, whose aim was to preserve the country's natural resources for their continued, sustainable use by future generations. Championed by President Theodore Roosevelt, through the mid-1900s, conservationists were successful in establishing the National Forest Service, the National Park Service, Fish and Wildlife Service, Soil Conservation Service, and National Wildlife Refuge system as well as numerous other beneficial natural resource protection programs.

At the end of World War II, another industrial revolution was clearly emerging, this one based upon the rampant use of chemicals to tame nature. The nuclear age had started and the construction of some of the largest, most complex chemical processing facilities in the world was under way in Hanford, Washington; Oak Ridge, Tennessee; and Aiken County, South Carolina. In addition to the nuclear arms race, U.S. industries were expanding to include the development and manufacture of oil-based plastics, synthetic pharmaceuticals, and agricultural chemicals. The impacts on the environment and public health from the wastes of this chemical-based industrial revolution were more insidious, long-lasting, and difficult to see than smoky skies and oil-slicked water. They include cancer, genetic damage, and ecosystem destruction. The battle cry that the use of the new technologies and products could cause environmental problems arose from Rachel Carson's examination of indiscriminate pesticide use on public health and species diversity described in her 1962 book *Silent Spring*. This carefully documented analysis alerted people and policy makers that more attention to the potential adverse

consequences of agricultural chemicals and, by logical extension, other modern industrial processes was needed. The book, although roundly denounced by the chemical industry, became the most important document in the American environmental movement and indeed one of the most influential books of the 20th century.

### FORMATION OF THE ENVIRONMENTAL PROTECTION AGENCY

As public awareness of environmental issues grew, the government made several attempts to address the patchwork of local and statewide laws and regulations that dealt with pollution and waste management. Although ineffective and having little enforcement power, the Federal Water Pollution Control Act and Air Quality Act of the early 1960s were the first serious attempts to establish an organized, nationwide system of environmental and pollution control laws. These laws were a good start, but it was not until the disillusionment with government and other American institutions in the late 1960s and early 1970s, fueled by the war in Vietnam, coupled with several highly visible environmental disasters, that overwhelming public pressure would finally lead to a substantial federal response.

On January 1, 1970, President Richard M. Nixon signed into law a groundbreaking piece of legislation: the National Environmental Policy Act (NEPA). For the first time, the federal government would be required to examine the environmental consequences of an action, be it a permit for a dam in Colorado or the construction of a public housing project in Illinois. NEPA both legitimized and emboldened environmentalists, both in Congress and at the grassroots level. Environmental protection was now firmly on the national agenda, and more than 20 million Americans took to the streets on April 22, 1970, to demand stronger and better enforced laws to improve air and water quality. A 1970 report by the Nixon administration on government reorganization argued strongly that an independent agency was needed to coordinate all of the new environmental initiatives.

President Nixon, not a strong believer in government intervention in free market activities, signed the executive order that created the Environmental Protection Agency on December 2, 1970.

### FOCUS AND MISSION

Although not a cabinet level department, EPA has a mission and powers that are some of the most far-reaching in the federal government. Early on, the

founders of EPA decided that they needed to operate independently of the executive and legislative branches. The EPA's prime directive is to "protect human health and the environment," and the decisions it makes must be viewed as objective, unbiased, and not influenced by any governmental agency, program, or political agenda. This can only be accomplished if it operates as a stand-alone entity. As part of its protective mission, EPA establishes and enforces environmental protection standards, conducts environmental research, and provides assistance to others addressing environmental pollution. The EPA also assists the Council on Environmental Quality (formed as part of NEPA) in developing and recommending to the president new environmental protection policies.

The new agency was assembled from and assumed responsibility for all of the environmental programs that had been previously dispersed throughout the federal government. This included air pollution control, water hygiene and solid waste, and the control of selected radiological management issues from the Department of Health, Education and Welfare. The Food and Drug Administration reassigned its control over tolerance levels for pesticides, and the Department of the Interior transferred the functions of the Federal Water Quality Administration as well as portions of its pesticide research responsibilities.

The first EPA administrator, 38-year-old William D. Ruckelshaus, quickly set about establishing the culture of the new agency as one that viewed the environment holistically and would serve as an advocate for the public's interests in a clean environment. The EPA considered economic issues in its decisions but would not be driven by or beholden to them. One of the EPA's first enforcement actions was to challenge the cities of Detroit, Cleveland, and Atlanta to meet newly promulgated clean air standards or face federal prosecution. This aggressive stance toward environmental advocacy and compliance, although somewhat moderated over the years as the environmental attitudes of the public and regulated community changed, remains one of the main tenets of EPA's organizational culture.

## ORGANIZATION AND OPERATIONS

On a national level, the EPA is managed by an administrator. Appointed in 2009, Lisa P. Jackson is currently the 12th EPA administrator and is responsible for managing more than 17,400 employees and overseeing an annual budget of almost \$11 billion. Supporting the administrator in Washington, D.C., are three official offices and nine assistant administrators whose functions include the following:

### Office of the Chief Financial Officer

Manages the agency's payroll and makes payments to EPA grant recipients, contractors, and vendors. Also handles all accounting and financial reporting for the agency, in compliance with the requirements of the White House Office of Management and Budget and the Department of the Treasury. At present, the position is held by Barbara Bennett.

### Office of General Counsel

Acts as the legal adviser to EPA and provides legal support for agency rules and policies. It also supplies legal advice for case-by-case decisions such as permits and response actions and legislation. At present, the position is held by Scott Fulton.

### Office of Inspector General

An independent office within EPA that is made up of auditors, program analysts, and investigators who help ensure the integrity of agency decisions and operations. Although it is part of EPA, Congress provides the OIG funding separate from the agency, to ensure its independence. At present, the position is held by Arthur A. Elkins, Jr.

### Assistant Administrator for Administration and Resource Management

Responsible for management of human resource functions (hiring, firing, benefits, etc.) for headquarters employees, as well as agency-wide human resources (HR) policy development, strategic planning, and the direction of EPA's human resource programs. At present, the position is held by Craig Hooks (Acting).

### Assistant Administrator for Air and Radiation

Develops national programs, technical policies, and regulations for controlling air pollution and radiation exposure. OAR also addresses pollution prevention and energy efficiency, indoor and outdoor air quality, industrial air pollution, pollution from vehicles and engines, radon, acid rain, stratospheric ozone depletion, climate change, and radiation protection. At present, the position is held by Gina McCarthy.

### Assistant Administrator for Enforcement and Compliance Assurance

Pursues enforcement actions and provides compliance assistance to areas that yield the most environmental benefit or reduce risk to human health. Enforcement and compliance actions are organized around environmental problems and broad patterns of noncompliance rather than provisions of single statutes. At present, the position is held by Cynthia Giles.

### **Assistant Administrator for International Affairs and Tribal Affairs**

Helps safeguard the health and environmental safety of individuals in the United States and abroad by leading EPA's efforts to address global environmental issues. Works with experts from EPA's other programs and regional offices, government agencies, foreign governments, and international organizations to identify environmental issues of mutual concern and implement technical and policy options to address them. At present, the position is held by Michael DePass.

### **Assistant Administrator for Environmental Information**

Manages the information life cycle in support of EPA's mission. Identifies and implements innovative information technology and information management solutions that strengthen EPA's ability to achieve its goals. It ensures the quality of EPA's information, and the efficiency and reliability of EPA's technology, data collection, and exchange efforts, as well as online access services. At present, the position is held by Malcom D. Jackson.

### **Assistant Administrator for Chemical Safety and Pollution Prevention**

Promotes pollution prevention through innovative partnerships and collaboration. Evaluates pesticides to safeguard all Americans, including children, and ensure pesticides used near food are safe and protective of the environment and ecosystems. At present, the position is held by Steven Owens.

### **Assistant Administrator for Research and Development**

The scientific research arm of EPA. Provides the science and technology information for the agency. Conducts research on ways to prevent pollution, protect human health, and reduce risk. At present, the position is held by Paul Anastas.

### **Assistant Administrator for Solid Waste and Emergency Response**

Offers policy, guidance, and direction for the agency's solid waste and emergency response programs. It develops guidelines for the land disposal of hazardous waste and management of underground storage tanks. Provides technical assistance to all levels of government to establish safe practices in waste management and administers the brownfields program, supporting state and local governments in redeveloping and reusing potentially contaminated sites. Responsible for the management of the Superfund program to respond to abandoned and active

hazardous waste sites and accidental oil and chemical releases as well as encourage innovative technologies to address contaminated soil and groundwater. At present, the position is held by Mathy Stanislaus.

### **Assistant Administrator for Water**

Works to ensure drinking water is safe as well as to restore and maintain oceans, watersheds, and their aquatic ecosystems. Protects human health, supports economic and recreational activities, and provides healthy habitat for fish, plants, and wildlife. At present this position is held by Peter Silva.

On a local level, EPA has divided the United States into 10 regions, each one assigned to a regional administrator, technical staff, and environmental protection goals, depending upon the needs of the geographic area it serves. At present, these position are held by the individuals listed in the table on page 221.

## **EPA REGIONAL OFFICES**

In addition to supporting and enforcing environmental initiatives developed in Washington, many of the EPA regions have their own subspecialties. For example, EPA Region 5 provides expertise related to air pollution and air pollution control, because of the presence of the many heavy industries and coal-burning power plants in this part of the country. Region 10 has extensive experience in the clean up of radiologically contaminated sites in response to the Hanford site along with other large, government-owned nuclear processing facilities throughout the area.

## **ACCOMPLISHMENTS AND FUTURE GOALS**

The record of accomplishment for the almost 40-year-old agency is impressive and includes the following major accomplishments:

- **1970s:** Establishes national air quality standards for the six most common types of pollutants: sulfur oxides, particulate matter, carbon monoxide, photochemical oxidants, nitrogen oxides, and hydrocarbons. Bans the use of dichlorodiphenyltrichloroethane (DDT) and works with Congress to pass substantial amendments to the Federal Water Pollution Control Act and Ocean Dumping Act. Starts phaseout of leaded gasoline and issues first permits regulating the discharge of municipal and industrial wastewater. Works with Congress to pass Safe Drinking Water Act. Bans the use of the

## EPA REGIONAL OFFICES

Region Number	2010 Administrator	Area Served
1 (EPA New England)	Curt Spalding	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont
2	Judith A. Enck	New Jersey, New York, Puerto Rico, the U.S. Virgin Islands, and seven Native American tribes
3 (EPA Mid-Atlantic)	William T. Wisniewski (acting)	Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and District of Columbia
4 (EPA Southeast)	Stanley Meiburg (acting)	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, and six Native American tribes
5	Bharat Mathur (acting)	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin, and 35 Native American tribes
6	Al Armendariz	Arkansas, Louisiana, New Mexico, Oklahoma, Texas, and 65 Native American tribes
7	Karl Brooks	Iowa, Kansas, Missouri, Nebraska, and nine Native American tribes
8	James B. Martin	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming, and 27 Native American tribes
9 (EPA Pacific Southwest)	Jarred Blumenfield	Arizona, California, Nevada, Hawaii, and 147 Native American tribes
10 (EPA Pacific Northwest)	Michelle Pirzadeh (acting)	Alaska, Idaho, Oregon, Washington, and Pacific Northwest Indian Country

pesticides heptachlor and chlordane. Works with Congress to pass the Toxic Substances Control Act and the Resource Conservation and Recovery Act (RCRA). Works with Congress to pass the Clean Water Act and substantial amendments to the Clean Air Act. EPA bans aerosol fluorocarbons and the manufacture of polychlorinated biphenyls (PCBs).

- **1980s:** Supervises the cleanup at Three Mile Island. Works with Congress to pass the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Identifies the first 114 Superfund sites. Works with Congress to pass the Asbestos School Hazard Abatement Act. Bans the use of the pesticide 1,2-dibromoethane (EDB). Works with Congress to pass Hazardous and Solid Waste Amendments Act, Superfund Amendments and Reauthorization Act, Asbestos Hazard Emergency Response Act,

and substantial amendments to the Safe Drinking Water Act. EPA sets standards for underground storage tanks, provides technical support urging the ratification of the Montreal Protocol (phasing out chlorofluorocarbons [CFCs]). Works with Congress to pass the Federal Insecticide, Fungicide and Rodenticide Act Amendments of 1988, the Indoor Radon Abatement Act, and the Ocean Dumping Ban Act.

- **1990s:** Works with Congress to pass the Pollution Prevention Act and the Clean Air Act Amendments. EPA issues final drinking water standards for 23 chemicals. EPA and New York mark end of offshore dumping of sewage sludge. Designates passive smoke a human carcinogen. Safe Drinking Water Act Amendments of 1996 passed. Finalizes leaded gas ban. Implements lead-based paint Right-to-Know. United States and Canada move to eliminate toxics in Great Lakes.



- **2000s:** Bans most uses of the pesticide Dursban. The United States signs Convention on Persistent Organic Pollutants. Awards brownfields grants to assess the contamination of abandoned industrial and commercial properties. Issues Strategic Plan for Homeland Security. Announces the Clean School Bus USA program. Issues the Clean Air Nonroad Diesel Rule. Establishes more protective eight-hour ozone and fine-particulate standards. Issues the Clean Air Interstate Rule and the Clean Air Mercury Rule. Becomes the first major federal agency to purchase green power equal to 100 percent of its annual electricity use. Strengthens standards for particulate matter with a diameter of 2.5 microns or less (PM<sub>2.5</sub>) particle pollution. Superfund marks 1,000th construction completion.

As the EPA looks toward the future, it faces some daunting challenges. The environmental implications of global climate change are going to dominate more of our economic and environmental policy decisions, and the EPA will be a central figure in the development of the policy approach to this vital issue. Coupled with climate change will be the need to develop programs that minimize impacts from expanded and more aggressive searches for dwindling natural resources while ensuring the sustainability of those resources for future generations. Ecosystem loss and habitat destruction related to population and development pressures will increase, and additional scientific research needs to be done on the effects of estrogen and other hormones (which are resistant to conventional treatment technologies) that are being found with alarming regularity in public water supplies.

Although EPA is decried by its detractors as slow, inefficient, and either too soft or too hard on the industries and practices it regulates, there is little doubt that the air is cleaner, the water purer, and wastes are managed in a more environmentally responsible manner. Although much remains to be done, the EPA has the infrastructure that will allow it to adapt to the demands of the American people for a clean environment and the needs of the U.S. economy to remain viable in an internationally competitive world.

*See also* ASBESTOS; BROWNFIELDS; CARBON MONOXIDE; CARSON, RACHEL; CHLORDANE; DDT; EDB; HANFORD RESERVATION; HEPTACHLOR; NO<sub>x</sub>; PARTICULATE; PESTICIDES; SAFE DRINKING WATER ACT; SULFUR OXIDE CONTROL TECHNOLOGIES; SUPERFUND SITES; THREE MILE ISLAND.

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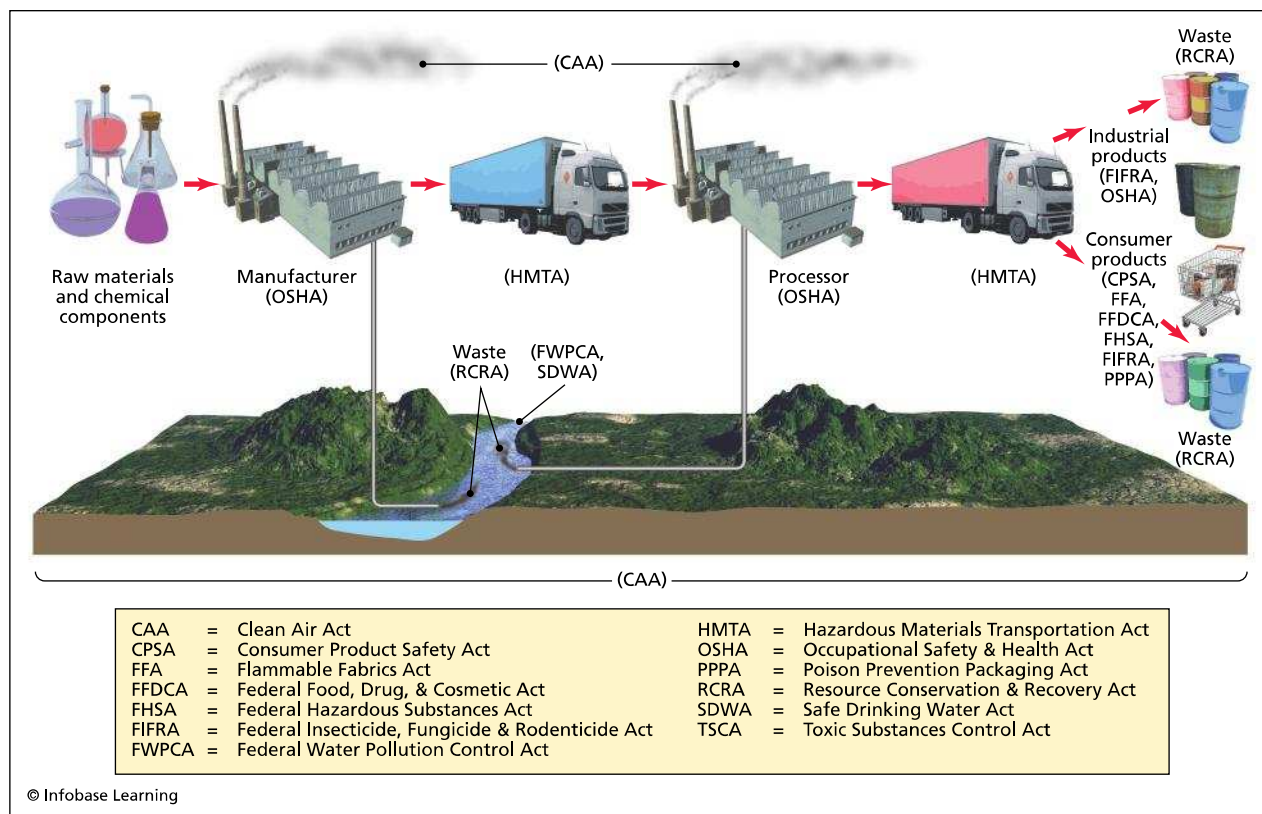
## environmental regulations overview

Environmental laws and regulations have been in effect in some countries for hundreds of years. Some of the earliest examples include passages in the Bible (Book of Genesis), Torah, and Quran commanding us to treat the Earth and its resources with respect. A more specific example occurred in 1402, when the English Parliament, in an early attempt to improve local air quality, passed a law banning the burning of coal in London.

Conservation laws that regulated the use and preservation of natural resources appeared regularly throughout American colonial times. In 1629, land use guidelines were promulgated in New England regulating plantation (farm) design and prohibiting activities that interfered with common resources such as water or damaged the property of others. Virginia passed laws regulating fishing, and Massachusetts, in the 1790s, developed some of the earliest statutes to promote wetland and coastal preservation. As industrialization continued, the western states evolved a complicated set of environmental regulations related to the use of water and mining. The modern body or set of environmental laws, however, did not begin to appear until the 1960s. They were based on three major legal precepts, common law, case law, and statutory law.

## BASES FOR ENVIRONMENTAL LAWS

United States common law is the general body of rules and precepts that originated in England and is not the result of legislative action, but rather derives its authority from unwritten principles related to



**Cartoon diagram illustrating many sources of pollution and media affected and the major federal regulations enacted to address them**

usages and customs that have been upheld by the courts over a long period. It is founded on a cultural view of fair, reasonable, and just actions. Common law can change over time and is intended to evolve with society. Under common law, a tort (civil wrong) from which relief is sought through the court can be based on every individual's or company's obligation not to cause harm to someone else as a result of its actions or inaction. A contract or written agreement with a company or person is not needed to bring a tort, only a claim that injury has occurred because of failure to avoid harm. The three most common torts related to environmental issues are nuisance, trespass, and negligence.

### Nuisance

A nuisance is an activity that interferes with the use of property through irritation, obstruction, or danger. Nuisances can range from obnoxious odors emanating from a nearby chemical plant (public nuisance, affecting many people) to a barking dog that will not be quieted (private nuisance, affecting an individual). In adjudicating nuisance torts, the courts weigh many factors, such as whether they are materially affecting physical or mental health, whether there are societal benefits (e.g., jobs) associ-

ated with the nuisance, and whether the nuisance predated occupancy of the property.

### Trespass

Trespass is an interference with the possession of property. This can include destruction or taking of personal property as well as unlawful or forcible entry. In environmental matters, trespass is most often claimed when air or water pollution physically migrates onto or under another's property and prevents the owner from using land, home, or business for its intended purpose.

### Negligence

Negligence is the unintended damage caused by a person's or company's failure to protect others from its actions. In evaluating negligence claims, the courts use the "reasonable man" test. What precautions would a prudent and sensible person have taken to avoid harm in this situation? The plaintiff must demonstrate that the defendant breached a duty or standard of care. One case illustrating a breach of the standard of care was a suit brought by Nissan Motor Corp against a Maryland shipyard. The shipyard chose to begin a large repainting operation on a windy day. As a result, windborne residues

## Epidemiology and Health Effects

A major tool used by toxicologists in the measurement of the disease-causing potential of a substance is an epidemiological study. Epidemiology is focused on the response of groups, populations, or communities to disease or injury. Epidemiologists study the factors that influence the distribution of illness or injuries in a population. They base their work on three fundamental precepts: (1) that the disease or injury does not occur at random and that there is a reason why certain groups or communities become ill or are hurt; (2) that the disease or injury has causal and preventive factors; and (3) that the disease or injury is not randomly distributed throughout a population.

Epidemiological studies attempt to identify the distribution and determinant factors of diseases and injuries in human populations. They are designed to study the differences in disease distribution in populations or population subgroups systematically and are used to test hypotheses concerning causal and pre-

ventive factors. There are four common types: cohort studies, case control studies, occupational epidemiological studies, and cross-sectional studies. Each is described in the following table.

### EXAMPLE OF CHOLERA

A good example of the value of epidemiology is the disease cholera. Cholera is a bacterial infection whose first symptoms include severe diarrhea, often accompanied by vomiting. The body rapidly loses fluid and salts, causing muscle cramps, unquenchable thirst, and cold, wrinkled skin. If lost fluids are not replaced, coma and death usually follow within 12–24 hours. Intravenous infusion of saline solution or ingestion of electrolyte solution is the preferred course of treatment. In the first half of the 1800s, four major cholera epidemics swept through England and Wales, killing almost 100,000 people. There was no cure, there was no treatment, and physicians were widely

**TYPES OF EPIDEMIOLOGICAL STUDIES**

Study Type	Description	Advantages	Disadvantages
Cohort	Follows a group of healthy people with different levels of exposure and assesses what happens to them over time	Exposure is evaluated and studied before the health outcome is known. This allows for a clear study and identification of causative factors.	Expensive, time-consuming, and logistically difficult to implement.
Case control	Investigates exposed individuals, or "cases," and nonexposed individuals, or "controls," and compares the health of both groups over time	Enables evaluation of rare outcomes without having to follow thousands of people. Quicker, cheaper, and easier to conduct than cohort studies.	Potential for bias is greater because only one type of health effect has been selected for evaluation.
Occupational	Selects and evaluates people working at particular jobs or with particular exposures	Workers often have substantially higher exposures to certain risk factors than the typical population. This increases the chance of detecting a health effect.	The working population is substantially different from the nonworking one. Makes it difficult to generalize to the overall population.
Cross sectional	Compares similar groups in terms of their current health exposure status and assesses their similarities often used to select populations for case control or cohort studies	Easy and quick to perform; provides a snapshot of a particular group.	A cause cannot be inferred, as only current health and exposure issues are evaluated.

divided on the cause and spread of the disease. Some blamed “bad air” from swamps, weak blood, poor nutrition, or even a “sinful state.”

In 1855, an English doctor decided to take a new approach to this mysterious disease. Dr. John Snow left his comfortable Harley Street office and went to a London neighborhood where cholera had been just been reported. His objective was to determine why the people in a particular group of apartment buildings had become sick, but not those across the street, or down the block. His 1855 paper “On the Mode of Communication of Cholera” is widely recognized as one of the first epidemiological investigations, and it established him as the founder of modern epidemiology.

Dr. Snow examined the medical histories of those who had the disease, their diets, their pets, their workplaces, their areas of travel, and their sleeping habits. He examined their apartments and, after a careful inspection of each building, found what he thought might be the cause. Dr. Snow noted that they all received their water from a single nearby well, and that this well was located very close to a cesspool used for the disposal of human wastes. He saw that the cesspool drain would leak or overflow, and human waste would sometimes enter the area near the well and probably mix with the drinking water. He checked other apartment buildings in the neighborhood where no cholera had been reported and found that those people had drawn their drinking water from a different well.

With this information, and drawing upon the concepts of disease causation being proposed in the relatively new field of bacteriology, Dr. Snow concluded that there was something in the cesspool-contaminated drinking water that was causing people to become sick. He proposed that drinking water supply systems should be isolated from those carrying human waste. In other words, keep feces out of the drinking water and the incidence of cholera should decrease. Although they seem obvious, Dr. Snow’s findings were controversial for the time and widely debated within the scientific and medical community. Eventually, as Snow successfully pressured local neighborhoods to implement some of his recommendations, the incidence of cholera began to decline.

Perhaps the most famous modern epidemiological study is the 1964 U.S. surgeon general’s report that conclusively linked smoking with lung cancer. Another is the Framingham Heart Study, which began in 1949. This study, which continues to track and evaluate to this day thousands of people living in Framingham, Massachusetts, provided some of the

first conclusive evidence that related heart disease to such lifestyle characteristics as a high-fat diet and lack of exercise.

### LABORATORY TESTING OF HEALTH EFFECTS

There are numerous ways a chemical or pollutant can impact a person or animal’s health. Administering different doses of a substance to test animals over their lifetimes and observing the related health effect or response is typically how noncarcinogenic toxicity is assessed. Using this method, toxicologists try to identify the lowest dose that causes an observable effect or response. These responses include damage to internal organs such as the kidneys or liver, behavioral modifications indicating changes in brain chemistry or function, or modifications in the animal’s blood chemistry suggesting interference with normal cellular activities. Once identified, this dose is designated as the lowest observable effect level, or LOEL. The LOEL is reported in milligrams of substance per kilogram of body weight, or in parts per million of substance in food.

#### Lowest Observable Effect Level (LOEL)

Hydramethylnon is a very effective delayed-action pesticide that is ideal for use in bait products. After a single feeding to target insects (usually roaches and ants), there are no immediate indications of poisoning. However, within a few hours, the insects become lethargic and stop eating. This condition progresses until the insects die, usually within 24–72 hours. Hydramethylnon interferes with the insect’s energy-producing mechanisms on a cellular level.

After the hydramethylnon bait is ingested, the roaches and ants serve as carriers of the active ingredient to harborage and colonies. Cockroaches are coprophagous; they eat their own feces and the feces of other roaches. They also feed on each other. After consuming a lethal dose of bait, cockroaches return to the harborage, where they excrete feces containing hydramethylnon. As other cockroaches consume the contaminated feces, they also receive a lethal dose. When the roaches die, other roaches may consume their contaminated carcasses. Field trials have shown that one cockroach that ingests a lethal dose of hydramethylnon can cause the death of more than 40 other cockroaches.

Ants carry the hydramethylnon-saturated bait to the colony, where the larvae digest and regurgitate it as a liquid to feed the queen and the rest of the colony.

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The delayed action of hydramethylnon allows foraging worker ants to return to the colony with the bait before they succumb to the poison.

To determine a (human) LOEL for hydramethylnon, the U.S. Environmental Protection Agency (EPA) used the results of a study on two generations of rats in which varying doses of this substance (0, 25, 50, and 75 mg/kg) were fed to 30 male and 30 female rats and their offspring. In this study, testicular degeneration was noted in five of 30 rats at 75 mg/kg and in one of 30 rats at 50 mg/kg. In 1998, on the basis of this incidence of testicular toxicity as well as the related dose-response curve, EPA set a LOEL of 50 mg/kg in food for hydramethylnon. Other toxicological experiments tended to support this LOEL, although data from a three-generation rat study caused the California Office of Environmental Health Hazard Assessment to establish a much lower LOEL of 0.12 mg/kg.

#### No Observable Effects Level (NOEL)

The next step in the assessment of noncarcinogenic effects was to identify the no observable effects level, or NOEL. This is the highest dose possible before there are any noticeable health effects. The animal species being studied can be exposed to a substance's NOEL and no adverse health effects will occur. The NOEL measured for hydramethylnon, based on dog, rat, and rabbit studies, is around 3–5 mg/kg. People, however, are genetically and physiologically more complicated than most laboratory animals and may be more or less sensitive to the chemical or substance being evaluated, so the NOEL is not considered a "safe level."

The NOEL practice is not without risk. Thalidomide, a drug developed in the 1950s and promoted as a sleeping pill for pregnant women, caused no adverse effects in test animals but resulted in severe birth defects in humans. Today, the standard practice for toxicologists is to divide the NOEL by a safety factor, usually 100, in order to calculate a dose or exposure standard that will be protective of the public health. For example, if the NOEL for a substance tested on laboratory rats were found to be 100 mg/kg, the "safe level" for humans would be 1 mg/kg. This safe level is also known as the reference dose (RfD). It is a numerical estimate of a daily oral exposure to the human population, including sensitive subgroups, such as children, that is not likely to cause harmful effects during a lifetime. RfDs generally are used for health effects that are thought to have a threshold, or low dose limit, for producing an adverse reaction. Some examples of RfDs for common contaminants are

provided in the table. The EPA determined the RfD for hydramethylnon at 0.0003 mg/kg/day. They also have classified it as a possible human carcinogen, and hydramethylnon's use in Europe was banned in 2003.

#### HAZARD QUOTIENT (HQ)

The RfD also is used in determining the hazard quotient (HQ) for a given substance. The HQ is the ratio of a single substance exposure level, over a specified period, to a RfD for that substance derived from a similar period. This ratio provides an indication as to the degree of hazard present as a result of exposure to that substance. As an example, Dalapon is a herbicide and plant growth regulator that controls annual and perennial grasses as well as cattails and rushes. Dalapon is selective, meaning that it kills only certain plants while sparing nontarget vegetation. This makes it very useful in improving the productivity and management of such large food crops as sugarcane and sugar beets. Dalapon also is used on fruits, potatoes, carrots, asparagus, alfalfa, and flax.

Dalapon is thought to be only moderately toxic to humans. Unless proper precautions are observed, skin and inhalation exposures may affect Dalapon production workers, pesticide applicators, and those working in agriculture. Acute exposure causes loss of appetite, slowed heartbeat, skin and eye irritation, and gastrointestinal disturbances such as vomiting and diarrhea. Dalapon also is an acid that may damage sensitive body tissues and especially the eyes. The EPA calculated an RfD for Dalapon of 0.03 mg/kg (of body weight) per day. No adverse health effects should occur to the most sensitive receptor from exposure to this concentration of Dalapon over a lifetime. If a person lives beside a farm where Dalapon is used, however, and the local health department finds that it has been detected in the well water at a concentration that results in an exposure of 0.02 mg/kg per day, a question is raised about potential health effects from exposure to this compound at this concentration. To determine whether there is cause for concern, the person should calculate the HQ.

Dalapon RfD = 0.03 mg/kg per day

Dalapon exposure = 0.02 mg/kg per day

HQ = exposure divided by RfD

HQ = (0.02 mg/kg per day) / (0.03 mg/kg per day)

HQ = 0.7

RfDs OF TYPICAL POLLUTANTS		
Type	Contaminant	Referenced Dose or Oral Slope Factor (mg/kg /day)
Metals	Arsenic	1.5
	Beryllium	4.3
Volatile organic compounds	Benzene	0.055
	Carbon Tetrachloride	0.13
	Chloroform	0.0061
	Tetrachloroethene	0.052
	Trichloroethene	0.4
Semivolatile organic compounds	Benzo(a) pyrene	7.3
	Benzo(b) Fluoranthene	0.73
	Pentachlorophenol	0.12
	Chrysene	0.0073
Pesticides/herbicides	Chlordane	0.35
	DDT	0.2
	Heptachlor	1.6
Others	PCBs	2

As long as the HQ is less than 1, it is below the threshold where a noncancerous effect is expected. In this case, the Dalapon-contaminated groundwater is safe for the time being, but it should be tested periodically to make sure the concentration does not increase.

### HAZARD INDEX (HI)

The real importance of HQs comes into play when there is more than one substance present to which a receptor may be exposed. If, for example, Aldicarb, a common herbicide, is added to the Dalapon-contaminated groundwater, a different HQ results. Aldicarb is a very aggressive insecticide used to control mites, nematodes, and aphids. It is applied directly to the soil for the protection of cotton, peanut, and soybean crops. Aldicarb has an RfD of 0.0013. If the concentrations in well water result in an Aldicarb exposure of 0.002 mg/kg per day, will people's health be affected? Calculating the HQ for Aldicarb, it is found that the HQ is less than unity (1), indicating that at this concentration, the risk is acceptable.

Aldicarb RfD = 0.002 mg/kg per day

Aldicarb exposure = 0.001 mg/kg per day

HQ = exposure divided by RfD

HQ = (0.001 mg/kg per day) / (0.002 mg/kg per day)

HQ = 0.5

The Dalapon that is also present in the water complicates the situation. Individual HQs do not consider the synergistic effects of exposure to more than one substance. For that, the hazard index, or HI, must be calculated. The HI takes into account exposure to more than one substance and is the sum of all the individual HQs. The HI is used to evaluate the risk resulting from exposure to more than one pollutant or from multiple exposure pathways (inhalation and ingestion).

The HQ for Dalapon is 0.7, and the HQ for Aldicarb is 0.5, both below unity (1) and, therefore, individually

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not a cause for concern. However, calculating the HI as follows:

$$HI = HQ1 + HQ2 + HQ3 + \dots$$

$$HI = HQ_{\text{Dalapon}} + HQ_{\text{Aldicarb}}$$

$$HI = 0.7 + 0.5$$

$$HI = 1.2$$

The HI is 1.2, greater than unity. Although separate HIs are usually calculated for chronic, subchronic, and shorter-duration exposures to specific target organs such as the kidneys or liver, the results from this example indicate that there is a significant risk of a potential adverse health effect from exposure to these substances at the reported concentrations. Corrective actions would be needed.

See also PESTICIDES.

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—by Robert P. Blauvelt

from paint spraying operations were deposited on cars stored at an adjacent parking lot. The court decided the shipyard was negligent and awarded Nissan appropriate monetary damages.

### Strict Liability

Another concept essential to understanding and applying common law to environmental claims is that of strict liability. A person or company can be held liable for damages for those activities that are considered hazardous, even if no negligence is proven. For example, walking a lion down a crowded sidewalk is dangerous, even if the lion has been trained, is well-fed, is wearing a muzzle, is declawed, and is on a leash, and there is a permit for the possession of the lion. Despite all these precautions, if the lion pounces on someone and injures him or her, the owner is held strictly liable. Similarly, the manufacturer of an extremely toxic chemical will be held strictly liable if a release occurs and injures residents living near the plant, even if the company has modern, state-of-the-art pollution control devices. Most of the environmental laws and regulations administered by the U.S. Environmental Protection Agency (EPA) (in particular the Comprehensive Environmental Response Compensation Liability Act or CERCLA), as well as many state agencies, are based on this concept of strict liability.

Case law is based on judicial decision and precedent, rather than on statutes passed by legislative bodies. Judges evaluate each claim or tort and

take prior decisions on similar matters into account before rendering a decision weighing those and other considerations. In contrast, statutory law is a set of written requirements established by a legislative or authoritative rule-making body to address a public need or clarify the functions of a governmental agency. Both case law and statutory law have played a role in the development and enforcement of environmental policies and regulations.

Modern environmental law includes a wide variety of statutory law, case law, and common law interpretations and precedents as well as federal, state, and local governmental regulations, policies, guidelines, and requirements. These laws and regulations attempt to control and manage the interaction of human activities with the natural environment including air, water, and soil, as well as the interaction of these media with the living ecosystem. Many environmental regulations and programs are interrelated and overlap, making them difficult to resolve. Ultimately, the system of environmental laws in the United States is designed to force those who conduct actions that could damage the environment to minimize potential environmental risks and to be liable if they harm public health or damage the use of soil, air, water, or the ecosystem. There are 12 major federal laws that govern human interactions with the environment, and EPA has delegated some or all of the enforcement responsibilities to the states that have equivalent environmental programs.

## NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

Passed by Congress in 1969 and signed into law by President Richard Nixon in 1970, NEPA (42 U.S.C. §§ 4321–4370c) is the first major statute in the United States that involved assessment and evaluation of the environmental consequences of human activity. NEPA was groundbreaking legislation and legitimized the environmental consciousness that had begun to sweep the nation. Its main purpose is to ensure that potential environmental impacts are given equal weight in federal decision-making processes to more traditional considerations such as economic and tax consequences, public and societal benefits, and military or diplomatic advantages.

### Requirements

NEPA requires that before any proposed federal action that has the potential to affect the quality of the human environment significantly can take place, a systematic and careful review of the environmental implications of that action must be undertaken. This is done through the preparation of an Environmental Impact Statement, or EIS. Using guidelines established by the President's Council on Environmental Quality (CEQ), the EIS must contain a description of the environmental impacts (both good and bad) of the proposed action, a list of adverse impacts of the proposed action, a description of reasonable alternatives to the proposed action, and an accounting of natural resources that are irreversibly and irretrievably committed by the proposed action. The NEPA requires that the EIS for a proposed action be made available for public review and comment. EISs can be large, complicated, and highly technical documents that take years to prepare.

Certain minor federal actions do not require the preparation of an EIS. These are referred to as categorical exclusions, or CatEx, decisions and include such actions as improvements to existing rest areas and truck weigh stations along interstate highways, bus and railcar rehabilitation, and alterations to facilities or vehicles in order to make them accessible for the elderly or handicapped. Other, more substantial but not environmentally insignificant actions can be evaluated under NEPA through a more streamlined process called an Environmental Assessment, or EA. The EA is a shortened, more concise version of the EIS, usually only 15–20 pages long. It contains many of the same elements as an EIS, but EAs are not required to have the weighty and exhaustive analyses that typically are contained in EISs. When a federal agency is not sure whether an EA or EIS is required, it can petition the CEQ for guidance and a finding of no

significant impact, or FONSI, can be issued, obviating the need for any type of environmental analysis. FONSIs are rarely granted when major federal actions are being contemplated.

The preparation of EISs for most major programmatic or construction activities has become widespread because so many private and state development activities rely on federal permits or funding. Usually, the federal or state agency sponsoring the project charges the prime contractor or engineering firm with the responsibility to prepare the EIS. A public scoping process is used to identify the environmental issues requiring in-depth analysis. Then the scientific evaluations of water, soil, air quality, ecology, and so on, are performed, and the data are compiled, analyzed, and presented in a draft EIS, or DEIS. This draft then is forwarded to the lead agency, the governmental body with the primary responsibility for the project. After review, the DEIS is published and made available for public comment. A final EIS, or FEIS, which must address each of the comments received during the public review period, is issued.

### Objectives

NEPA and the EIS process are not intended to prevent damage to the environment, and federal agencies can still approve projects that have significant adverse environmental impacts. NEPA simply requires that these adverse impacts be identified and evaluated and that the agency consider the alternatives. If the agency deems that the benefits outweigh the negative environmental consequences of a project, they may still approve it. NEPA allows the public concerns to be heard, assessed, and included in that evaluation. It also ensures a high degree of transparency in the decision-making process and provides an opportunity for those most affected to apply political and scientific pressure to ensure adverse effects are mitigated as much as possible, even if project costs increase.

NEPA remains one of the cornerstones of American environmental law and policy, and its effective and efficient implementation continues to be a key goal of the CEQ and most federal agencies. Although many governmental bodies chafed early on at what they saw as interference with their regulatory authority, NEPA has now become fully integrated into the policy and strategic planning components of both federal and state governments.

## CLEAN AIR ACT

First passed in 1967 as a set of guidelines to help states improve their air quality, the Clean Air Act (CAA) has evolved into one of the most dominant



pieces of federal environmental legislation currently in effect. As air quality continued to deteriorate in the United States through the 1970s, it became clear that the technical and political issues associated with air pollution were too encompassing for the states to address by themselves. As a result, in 1977 and in 1990, the CAA was amended and became a very stringent command-and-control regulatory program.

### Requirements

The Clean Air Act of 1977, and its amendments in 1990, established the National Ambient Air Quality Standards (NAAQS), which limit the amounts of pollutants an industrial or commercial facility can discharge into the atmosphere. The limits are intended to be protective of public health, for both short-term (eight hours) and long-term exposures. The NAAQS standards have been the subject of numerous legal actions, both pro and con.

Under the CAA, each state has to demonstrate how it intends to achieve compliance with NAAQS. This is done through a State Implementation Plan, or SIP. The SIP must list the allowed emissions and their levels. It must describe the monitoring program for compliance with the emission limits and procedures to review and approve new major sources of air emissions (more than 100 tons [90 metric tons] of pollutants per year) and minor sources (less than 100 tons [90 metric tons] per year) that are proposed for construction. The SIP must account for pollution that may drift into the state from areas outside its boundaries and have an enforcement program designed to track down and punish polluters. The SIP is intended to be a “living” document, one that is revised and updated on a regular basis to take into account changing economic conditions and technological advances. For those states that fail to implement and update their SIPs, the federal government can withhold highway funds and implement other punitive measures.

Those portions of a state that are unable to achieve compliance with NAAQS regularly are called nonattainment areas and are subject to special controls under a SIP. If an industry wishes to expand or build a new facility and increase the level of air pollutants it will emit in a nonattainment area, it must obtain reductions in these same pollutant levels from other businesses, often at ratios of greater than one for one. For example, if a utility wants to build a new power plant that will emit 50 tons (45 metric tons) of particulate matter with a diameter of 10 microns or less (PM<sub>10</sub>) per year within a nonattainment area, it must find other facilities within the same area that are willing to reduce their particulate discharges by a similar

amount, or even more. The utility can offer to buy PM<sub>10</sub> emission credits—levels of particulate that other businesses are permitted to emit, but are not emitting because of shut-down production lines, less business, or the like. The utility can apply these credits toward the operation of its new power plant.

Emission credit trading is a lucrative business in certain parts of the United States. One ton (0.9 metric ton) of sulfur dioxide emissions has a market value in some areas of about \$10,000 per year. Many environmentalists view this as a loophole in the regulations that allows businesses to continue to emit high levels of pollutants. Many companies praise it as an innovative way to keep the economy growing and let the marketplace decide the value of projects.

Existing sources of air pollution in attainment areas must comply with the much stricter requirements in the SIP related to the New Source Review (NSR) portion of the Clean Air Act for the Prevention of Significant Deterioration, or PSD. One of the major requirements of the New Source Review PSD is that the facility must install and utilize the Best Available Control Technology (BACT) to manage its emissions. BACT achieves the maximal degree of emission reduction possible, taking into account cost, energy, and environmental factors. These technologies typically are very costly to install and operate.

For new sources of proposed air pollution in nonattainment areas SIP standards are even stricter. They must use technologies that achieve the Lowest Achievable Emission Rate (LAER). The LAER test includes not only emission technologies for the proposed new emission source, but for any other similar technology in a related business. For example, if a coal-fired power plant claims that a certain type of wet scrubber fulfills its LAER obligation, the regulatory agency can survey the mining industry, the chemical industry, and other businesses where similar emissions are produced, and, if a better device is identified, they can require that the power plant install it even if it is not typically used to control power plant emissions.

One area of the CAA that has been controversial is the modification rule under New Source Performance Standards (NSPS). As required by CAA, EPA must promulgate emission standards for certain industries that must be met when they upgrade or expand their businesses. NSPS are much tougher than the emission standards that many facilities were originally permitted to operate under before CAA was passed. The controversy is related to trying to define a modification. Many environmental groups claim that any type of major maintenance (e.g., rebuilding or replacing a worn turbine), change

in a production line, or increase in production volume is a major modification and should require the facility to meet the more stringent NSPS. This situation requires the installation of expensive Maximum Achievable Control Technology (MACT). These are air pollution control devices that result in the maximal degree of pollution reduction that is achievable given economic, energy, and environmental considerations in the source category (power plants, chemical factories, etc.). Business groups assert that they need some flexibility in the application of NSPS in order to operate their plants efficiently and respond quickly to changes in market conditions. EPA generally applies the NSPS upgrade requirements when a facility has an increase in emissions related to a physical or operational change in plant activity. Both industry and environmental groups have not been satisfied with this approach, and the enforcement of NSPS is currently being adjudicated.

CAA imposes limits on the emission of sulfur oxides, one of the major causes of acid rain, as well as establishing class I air quality areas (primarily near national parks) where additional restrictions are placed on businesses that emit air pollutants. Upper atmospheric ozone layer protections also are included in the CAA, which requires the phaseout of chlorofluorocarbons and other ozone-depleting substances. Finally, the CAA established, under a section called Title V, one of the most rigorous operational permitting programs in the world. Under Title V, each plant or business that emits 100 tons (90.7 metric tons) of air pollutants or more per year must inventory its sources, estimate the amount of pollution from each source, and propose a plan to eliminate that emission or bring it into compliance with applicable CAA requirements (PSD, NSPS, etc.).

Extensive monitoring requirements are written into the Title V permit, and penalties for noncompliance can range up to \$25,000 per day. In 2009, the EPA carried out 10,000 inspections of Title V facilities and imposed fines of almost \$2 billion for various operational and monitoring infractions. They also referred several hundred cases to the Justice Department for possible criminal prosecution. The CAA is complex and far-reaching legislation that has given the federal and state governments the tools to identify and regulate industrial and commercial (stationary) sources of air pollution. It is one of the main reasons why the skies over America are clearer and the air easier to breathe than only a few years ago.

### CLEAN WATER ACT

The short-term environmental objective of the Clean Water Act (CWA), passed in 1972 as an amendment

to the Federal Water Pollution Control Act, is to make every water body in the United States “fishable and swimmable.” Longer term, it seeks to restore and maintain the chemical, physical, and biological integrity of the nation’s water. These lofty goals are to be attained through a variety of mechanisms inherent in the act. These include:

- preventing discharges to surface and groundwaters, except those that have been authorized in compliance with provisions of the CWA
- establishing a system for preventing, reporting, and cleaning up spills
- setting limits on the amounts and types of pollutants that can be discharged and making sure that those discharges are controlled and monitored through a facility-specific permit program
- vigorously and uniformly enforcing permit conditions and those that violate the provisions of the CWA

### Requirements

The CWA broadly defines a pollutant as anything that is added to the navigable waters of the United States including solids, liquids, and thermal pollutants. To qualify for inclusion under the CWA, the pollutant does not necessarily have to be toxic or dangerous, but it must be connected to interstate commerce. The CWA also differentiates between a point source and a nonpoint source of pollution. Point source pollution is anything that comes out of a pipe, ditch, channel, or other human-made conveyance. Nonpoint source pollution includes discharges from less well-defined mechanisms, such as runoff from farm fields or roads.

Regardless of its source, the CWA requires that discharge of a pollutant must be under the terms of a National Pollutant Discharge Elimination System (NPDES) permit. These permits typically are issued for five-year intervals and require a description of the discharged pollutants, their concentrations, and monitoring plans. The NPDES permitting process is long and complicated and includes ample opportunity for public input and comment. Once issued, NPDES permits give the regulatory agency wide authority to enter an industrial establishment and inspect the discharge.

Under the CWA, effluent discharge guidelines have been established for most types of industrial operations. These guidelines set limits on the types of discharges. For pollutants typically associated

with domestic sewage treatment (BOD, TSS, fecal coliform, pH, and oil and grease), the permittee is required to install Best Conventional Technology, or BCT. These are technologies that are effective and able to remove contaminants for a reasonable cost. This is the simplest level of treatment allowed under the CWA and is consistent with the relatively low level of risk posed by this type of pollutant.

For other types of industrial pollutants, the CWA requires that dischargers use Best Practical Control Technology (BPT). These are pollution abatement systems that are the average of the best for a particular type of industry. To establish BPT requirements, EPA surveyed facilities they considered superior in terms of wastewater control and mandated that all industries use technologies at least equivalent to those.

For the most toxic pollutants, Best Available Technology, or BAT, must be used. These can achieve the maximal, feasible pollution reduction for a given industry. In designating BAT, the EPA also considers nonpollutant reduction factors such as environmental impacts, energy requirements, and economic achievability.

The use of BCT, BPT, and BAT technologies applies only to wastewater discharges that were in operation prior to the passage of the CWA in 1972. More recent sources of wastewater discharges must comply with New Source Performance Standards (NSPS) requirements. These can be more stringent than BAT standards and require the installation of advanced and expensive wastewater treatment systems. They are designed to achieve the greatest reduction in pollutant concentrations possible, including the elimination of all pollutants from the waste stream. The need to comply with NSPS is hotly contested by many industrial facilities because these technologies often require major overhaul and upgrade of nonwastewater systems and can change entire production line operations.

Under the CWA, each state must establish water quality standards for its surface water bodies, and permits then are issued with those discharge limitations for pollutants. A practical example of these standards might be that to ensure trout propagation, there can be no more than 0.2 mg/L of arsenic in a certain river. Therefore, a state will not issue a NPDES permit that allows an industrial discharge into that river, taking into account dilution, mixing, and other natural attenuation factors, to exceed 0.2 mg/L. This concept is slowly being expanded into a watershedwide basis through the Total Maximum Daily Load (TMDL) part of the CWA.

TMDLs are quantitative limits on pollutants that can be discharged from all sources into a watershed.

TMDLs are established for the entire watershed and often require industrial facilities to meet even lower pollution discharge limitations. Under TMDL, if the state or EPA determines that the ecologically “safe” amount of arsenic for a given watershed is 3 mg per day, then all permit limits for industrial facilities discharging wastewater into that watershed will have their limits adjusted to the new standard. This means that a facility that had been allowed to discharge 0.2 mg/L of arsenic in 100,000 gallons (378,541 L) of wastewater per day, or 2.8 ounces (80 g) of total arsenic, may now only be permitted to release 0.002 mg/L of arsenic in that same volume of wastewater (0.03 ounces [0.8 g] of total arsenic), so that the total (TMDL) discharge of arsenic into the watershed river from all sources is 3 mg/day.

The CWA also establishes requirements and provides funding and technological advice for the control of storm-water discharges including runoff from city streets, parking lots, and industrial facilities that is diverted directly to a surface water body without treatment. In particular, this part of the act is intended to help municipalities address combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs). In many older communities around the United States, the storm-water and sanitary sewer systems are combined into one. During a heavy rain, the city’s wastewater treatment system is often overwhelmed, and, to prevent flooding or damage to equipment, the operators must bypass the treatment plant and discharge raw sewage, mixed with rainwater, into the receiving stream or river. As these CSOs and SSOs move through the watershed, they can result in significant ecological impacts (e.g., fish kills) or threats to public health (bacterial infections).

Not all industrial discharges release their pollutants directly into “the Waters of the United States.” Many are connected to sewers that drain to municipal sewage treatment plants or publicly owned treatment works (POTWs). In this case, an industrial facility must first pretreat its wastewater to meet certain standards established for that particular industry. These pretreatment programs are intended to protect the integrity of POTW operations as well as the health and safety of their operators by making the industrial user remove or neutralize the most toxic or dangerous components of its process flow stream.

The CWA also created requirements for wetlands protection, coastal zone management, and dredging and filling of waterways. Facilities storing more than 1,320 gallons (5,000 L) of petroleum products that, in the event of a spill or some other catastrophic event, could reasonably be expected to enter a waterway must prepare and maintain a Spill Prevention,

Control and Countermeasure (SPCC) plan. This plan describes reporting procedures and cleanup of a release of oil that enters a water body or threatens to enter it.

### Objectives

The EPA and the states administering their own NPDES-equivalent programs can bring a variety of enforcement actions against those not complying with CWA requirements. An administrative order or directive can be issued for permit violations levying fines up to \$11,000 per day and requiring the discharger to achieve compliance within a specified time frame. For more serious violations of intentional discharge of pollutants in excess of permit limits, a civil action in federal court can be initiated. In this case, monetary penalties are much higher and cessation of all discharges can be ordered, effectively closing the business. Finally, for the most egregious violations of discharging toxic chemicals without a permit or failing to comply with administrative or court orders, criminal enforcement proceedings can be instituted and can result in personal fines and incarceration for the business owners or wastewater treatment plant operators.

The CWA also allows, under certain circumstances, any affected person to initiate his or her own enforcement action against an industrial discharger. These citizen suits typically are brought by environmental advocacy groups when the EPA or state agency is not “diligently prosecuting” a NPDES permit violation. Most of these suits are settled with monetary awards allocated to improve the discharge control technology or to support a local environmental restoration project of interest to the parties bringing the suit.

### SAFE DRINKING WATER ACT

In its most recently amended form (1996), the Safe Drinking Water Act (SDWA) continues its mission to protect the purity and safety of drinking water. The SDWA regulates private companies and utilities that find, treat, and distribute water to private homes and businesses. SDWA establishes a monitoring system designed to identify and control contaminants and to inform customers about the quality of the water they are drinking.

### Requirements

The SDWA applies to community water systems with 15 service connections used by year-round residents or that regularly serve at least 25 year-round residents. A noncommunity water system typically serves only a limited number of people for a short

duration such as a well in a recreational (campground) area that is only open during the summer. Homes or private residences supplied with water from a single well are not regulated under SDWA.

The SDWA establishes a set of water quality standards that must be met in order to remain in compliance. These standards are divided into National Primary and National Secondary limits. National Primary Drinking Water Regulations (NPDWR) include compounds known to have adverse effects on public health, and a Maximum Contaminant Level Goal (MCLG) is established for each of them. The MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow a margin of safety and are nonenforceable public health goals. They often are not economically or technologically achievable by water supply companies or utilities. For enforcement purposes, the EPA uses the compound’s MCL, or Maximum Contaminant Level. This is the highest concentration of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible on the basis of the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.

If chlorine is used to disinfect water, a series of breakdown compounds can form (e.g., trihalomethanes). The amount of these compounds that is allowed in public water supplies is regulated by the Maximum Residual Disinfectant Level (MRDL), the highest level of a disinfectant allowed in drinking water. Obviously, the addition of a microbial disinfectant is necessary to control harmful bacteria, and the Maximum Residual Disinfectant Level Goal (MRDLG) is the level of a drinking water disinfectant below which there is no known or expected risk to health. The EPA is required by the SDWA to review the NPDWRs every six years to determine whether they need to be revised.

National Secondary Drinking Water Regulations identify compounds that do not pose a health risk at levels above Secondary Maximum Contaminant Levels (SMCLs) but may cause water users to experience adverse aesthetic effects. The water may appear discolored or have an unpleasant taste or odor. SMCLs are not enforceable standards under federal law but have been established as generic guidelines to help water purveyors assess the overall quality of their product.

SDWA regulations require that the water supplier provide annual reports to its customers with a consumer confidence report. This report describes the quality of the water delivered and characterizes risks related to exposure from contaminants present in the water. For example, if a water utility



or company detects radon at concentrations above NPDWR MCLs, the consumer confidence report must describe the associated risks and health consequences related to ingestion of those amounts as well as the actions of the supplier to restore water quality to compliance with MCLs.

The SDWA gives the EPA or state the authority either to take over or to shut down a water purveyor not only for documented violations, but also if the supplier is acting in a manner that may threaten or put at risk the health of its customers. Similarly, private citizens can bring an enforcement action if the regulatory agencies are not diligently requiring compliance with SDWA regulations.

Water suppliers are required to utilize Best Available Technology (BAT) for each NPDWR. Not all systems, however, have the financial or technical ability to implement each BAT technology. Under SDWA, the EPA can issue variances and exemptions for a NPDWR. These allow the company or utility to continue to supply water, even though it may contain contaminants above MCLs. Both variances and exemptions, which can only be issued if there is no unreasonable risk to the public, are not permanent and are intended to provide time for the supplier to upgrade and bring its system into compliance with SDWA regulations.

### Objectives

The SDWA provides funds for a revolving loan system to help small water suppliers (those serving fewer than 10,000 customers) to finance technological and water distribution improvements. Companies providing bottled water also must conform to most SDWA regulations, including periodic sampling to demonstrate compliance with MCLs. One unintended consequence of the SDWA is that water purveyors are becoming bigger. Smaller systems generally are not able to afford the improvements and upgrades periodically required to their treatment systems. Smaller community based systems are being merged or acquired by larger, nationally or regionally based companies that can spread those costs over a much larger rate base.

## RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)

The Resource Conservation and Recovery Act (RCRA) became law in 1976 and was modified in 1984 by the Hazardous and Solid Waste Amendments (HSWA). Both pieces of legislation are focused on managing and ensuring the safe, environmentally appropriate disposal of the more than 50 million tons (45 million metric tons) of hazardous solid

waste generated annually within the United States. RCRA/HSWA mandates that producers of hazardous waste provide “cradle to grave” care of the material to prevent its unintentional release or unauthorized disposal.

### Requirements

Divided into 10 subtitles (labeled A through J), RCRA begins by establishing two definitions of what a hazardous waste is. Hazardous substances are those that cause or result in an increase in mortality rate or serious irreversible or incapacitating illness to people or represent a substantial present or future threat to human health or the environment if they are not managed and disposed of properly. A waste, that industrial residue that has no economic or recycling value or will not be reused in another manufacturing process, is considered hazardous if it (a) has certain characteristics of reactivity (violent instability in the presence of water or other chemicals), ignitability (low flash point), corrosivity (very low or very high pH), or toxicity that makes it inherently unsafe to handle or dispose of in a landfill; or (b) has been included in a series of lists developed by the EPA of waste compounds that the agency has determined to be hazardous by their very nature. The EPA has published a series of tables, the parameters against which a waste is tested to determine whether it is hazardous by characteristic. One example is that of “listed” hazardous wastes, those found by the EPA to be hazardous on the basis of the manufacturing processes that produced them.

Under RCRA’s Mixture Rule, if a hazardous and a nonhazardous waste are combined, the resulting product is considered hazardous. This rule was included to prevent industrial facilities from taking their hazardous waste, mixing it with plant trash or other debris, and disposing of it for much less money as nonhazardous waste. If a company generates hazardous waste, it must notify the EPA and describe the type and amount of waste material it is producing. The EPA then adds the company to its national database and issues it a hazardous waste generators number. Generators of hazardous waste are allowed to accumulate the material on site in special secure storage areas, but the hazardous waste must be disposed of at least once every 90 days. The storage areas must meet certain standards for, among other things, aisle space, inspection frequency, spill containment and control, and separation of incompatible wastes that might react violently if accidentally mixed together. Generators can either be small, producing 45–455 pounds (100–1,000 kg) per month, or large, producing more than 455 pounds (1,000

kg) per month. Each category of generator must comply with a specific set of waste-management and record-keeping provisions.

When disposing of the waste, a generator completes a shipping form called a Uniform Hazardous Waste Manifest. This form accompanies the waste from its point of origin to its point of disposal. Every time the waste changes hands, the manifest is signed, and eventually, upon arrival at the disposal facility, a completed manifest is returned to the generator and one copy is sent to either the EPA or the state regulatory agency. The use of the manifest ensures accountability for the hazardous waste and prevents unauthorized disposal. If a generator does not receive a copy of the manifest signed by the disposal facility within 15 days of waste shipment, the generator is required to file an Exception Report, notifying the EPA and/or the state agency that the hazardous waste shipment is unaccounted for. The EPA and/or the state agency then begins an investigation to determine the status of the material.

Trucking companies that transport hazardous waste to disposal facilities must also register with EPA and federal and state departments of transportation (DOTs). They operate primarily under a set of regulations issued and enforced by the DOTs, the Hazardous Materials Transportation Act (HMTA). This act and its related regulations regulate the types of containers to be used in shipping hazardous wastes, shipping method (rail, air, etc.), container labeling, as well as many other requirements.

Those facilities that either treat their own hazardous wastes on site or receive hazardous wastes from others for storage longer than 90 days are called TSD (treatment, storage, and disposal) facilities. TSDs are subject to very stringent regulatory oversight by EPA and state environmental agencies. TSDs can be landfills, surface lagoons, incinerators, or liquid/solid stabilization and treatment plants.

Under RCRA/HSWA, TSDs are required to obtain a permit to operate before they accept any wastes. Each facility must contain security systems to prevent accidental or unauthorized access to waste storage or processing areas, have provisions for regular inspections of waste handling areas, provide medical monitoring and appropriate training to employees in hazardous waste management procedures, and have an internal alarm as well as fire, spill control, and decontamination equipment on-site. TSD facilities in environmentally sensitive areas must comply with other special standards established for operations in those types of settings to reduce the risk of catastrophic equipment or process failure.

Hazardous waste incinerators must meet all Clean Air Act requirements, particularly those involving

the use of MACT. They must have continuous monitoring and automatic shut-down controls and be capable of achieving destruction and removal efficiency (DRE) of at least 99.99 percent.

RCRA/HSWA regulations mandate that TSDs reserve enough money with a third party so that the facility can be properly closed. This “financial assurance” is used to remove any hazardous waste left on the premises and decontaminant equipment. The funds also must be sufficient for 30 years of postclosure monitoring and maintenance, if TSD activities involved permanent, land-based disposal of wastes. Hazardous wastes must be qualified under the Land Disposal Restriction (LDR) program of RCRA/HSWA before being placed in a landfill, surface impoundment, or similar land-based disposal unit. LDR requires that liquid hazardous wastes or hazardous wastes that may leach hazardous constituents into the soil or groundwater be stabilized and tested prior to disposal. Results of this testing need to demonstrate that the toxicity of the wastes has been reduced and that the likelihood of waste migration from the disposal unit has been minimized.

LDR also requires the placement of wastes in specially designed disposal cells that have double plastic or clay liners, separated by a sand layer that captures liquids and sends them to a leachate collection system. Landfills and waste piles also must be finished with high-integrity clay or plastic caps covered with layers of crushed stone and topsoil that reduce infiltration of precipitation, minimize erosion, and prevent intrusion into the waste by burrowing animals. Gas venting and collection systems typically are incorporated into cap design, depending upon the type of waste being placed into the disposal unit. A series of monitoring wells are installed around the outside of the landfill or waste pile, and groundwater samples from them are tested on a regular basis to determine whether wastes or waste constituents are escaping from the disposal unit. If a release is detected, the TSD must perform Corrective Action.

Corrective Action is the part of RCRA/HSWA that requires a TSD facility to investigate and remediate releases from their solid waste disposal (management) units, or SWMUs. This is done through a RCRA Facility Investigation, or RFI. The RFI process investigates the placement of wastes in the SWMU, collects soil and groundwater samples in and around the SWMU, and identifies the amount of escaped waste and where it has gone. A RCRA Corrective Measures Study, or CMS, is then performed to evaluate the best way to stop and clean up the release. Once EPA or the state agency reviews and evaluates the CMS, the final step is the Corrective Measures Implementation (CMI), where the remedial solution is designed and

implemented. Wastes generated from the remediation of a leaking SWMU are sometimes placed in a special type of landfill called a Corrective Action Management Unit (CAMU). Design standards for CAMUs are not as stringent as those for generated wastes but still require liners and other environmentally protective systems.

RCRA/HSWA regulates not only industrial or commercial hazardous waste materials but also a number of items that many people would not normally consider hazardous. These include:

- Universal Wastes are those that are widely manufactured and generated and include nickel-cadmium batteries, returned pesticides, mercury filled devices, and fluorescent bulbs. Generators of these wastes must use special packaging and labeling and dispose of them at authorized facilities.
- Outdated unused, used, or fired munitions called “unserviceable munitions” are regulated under EPA’s Military Munitions Rule (MMR) and include chemical warfare and riot control agents. MMR also covers non-military disposal activities (police and federal law-enforcement firing ranges, etc.).

Medical wastes, used or unused syringes, medical devices, and human tissue currently are not regulated by RCRA/HSWA. In 1988, in response to washing up of medical waste on beaches in several mid-Atlantic states, the EPA established a demonstration program that temporarily included medical wastes as part of RCRA/HSWA. That program ended in 1992 and has not been renewed.

Used oil from motor vehicles also is not covered by RCRA/HSWA regulations, if the oil is destined for recycling. The EPA has established standards for those facilities accepting used oil for recycling.

### Objectives

The intent of RCRA/HSWA is to reduce the amount of hazardous waste being generated in the United States by encouraging generators to use more environmentally safe alternatives and to seek alternatives to land disposal. RCRA/HSWA has also been extremely effective in imposing order and accountability in the waste management climate.

### Underground Storage Tanks

Subtitle I of RCRA/HSWA addresses the regulation of underground storage tanks (USTs). There are approximately 700,000 UST systems in the United States, and the EPA estimates that about one-third

of them have leaked or are leaking into the soil or groundwater. USTs have long been recognized as one of the most common sources of soil and groundwater pollution, and several billion dollars is spent annually on the cleanups associated with those releases.

A UST is defined as any tank with more than 10 percent of its volume located below ground including associated piping. Septic tanks, process flow-through tanks, or emergency spill control tanks are not USTs. Tanks with a storage capacity of less than 110 gallons (416.4 liters), farm or residential tanks holding less than 1,100 gallons (4,164 liters) of motor fuel, and tanks of any size used for the storage and on-site consumption of heating oil also are exempt. There are numerous other exemptions for specialty UST systems, including those holding hazardous waste, in basements or vaults, and those used in wastewater treatment.

An owner or operator of a UST system must register it with the EPA or equivalent state agency and ensure that the tank meets the following requirements:

- Overfill prevention—Many releases associated with USTs occur during refilling or transfer operations. New and existing tanks must have systems installed on them that automatically shut off flow when the tank is 95 percent full. These overfill protection devices are similar to those used at gas stations, where a sensor in the nozzle shuts off flow if back-pressure is sensed.
- Spill Prevention—Releases often occur when the fill pipe is detached from the top of the tank. Even the few drops to cupful of oil or gasoline that could discharge from the fill nozzle, if repeated over time, can result in significant soil or groundwater contamination. Catch basins around the fill port must be installed on USTs to recover residual or excess fluids released during filling operations.
- Leak Prevention—New USTs, and their piping systems, must be installed with leak prevention systems such as double walls or special linings or coatings. For metal tanks, this includes corrosion protection systems that prevent naturally occurring decay of the metal walls.
- Leak Detection—Subtitle I regulations require tank systems to have a device that alerts the owner or operator in the event of a leak. These can include an in-tank sen-

sensor that detects changes in inventory or the presence of water, an out-of-tank sensor that measures the occurrence of product fumes in adjacent soil, or a sensor between the walls of double-walled tanks. In some cases, monitoring wells are drilled around the UST and special sensors are installed that sound an alarm if the tank contents migrate into the well. Out-of-tank systems are not preferred, because by the time an alarm sounds, the release has already occurred.

If a release occurs, sometimes called a leaking underground storage tank (LUST), it must be reported to either the EPA or the agency approved by the EPA to oversee remedial activities. Typically, these activities include removing the UST from service, emptying it, locating the source of the release, either fixing or replacing the damaged tank or piping, and implementing soil and groundwater cleanup activities. For most UST releases, contaminated soil is excavated and shipped to an off-site disposal facility. Waste released from the tank is pumped from the groundwater, and monitoring wells are installed to measure the distance of migration. Depending upon the nature and extent of the contamination, active groundwater treatment may be required, or, in less severe, low-risk cases, only long-term monitoring may be necessary to demonstrate that contaminant concentrations are slowly decreasing. Many states have their own, more extensive specialized LUST release reporting and cleanup protocols and procedures and require that cleanup be performed by qualified and licensed professionals.

Federal UST regulations require facilities to maintain financial responsibility or assurance, usually an insurance policy that provides funds to clean up a release from a tank system. Financial assurance also compensates third parties if they are injured as a result of a tank release. The EPA and many states provide funds in the form of low-interest loans or grants from gasoline sales tax for the cleanup of releases from USTs where the responsible party is unable or unwilling to implement necessary tank closure or cleanup activities.

### **COMPREHENSIVE ENVIRONMENTAL RESPONSE COMPENSATION AND LIABILITY ACT (CERCLA)**

Signed into law by President Carter on December 11, 1980, and amended in 1986 by the Superfund Amendments and Reauthorization Act (SARA) and again in 2002 by the Small Business Liability Relief and Brownfields Revitalization Act, CERCLA/SARA represents the final major legislative initiative

to address environmental protection in the United States. RCRA/HSWA establishes requirements for active, operating facilities and businesses generating and managing hazardous wastes, and CERCLA/SARA does the same for abandoned or inactive sites where uncontrolled hazardous wastes pose an unacceptable risk to public health or the environment.

### **Requirements**

An important part of CERCLA/SARA was the establishment of funds through a tax on certain types of petroleum and chemical products to clean up abandoned waste sites. This funding source, supplemented by general tax revenue and nicknamed Superfund, provides the EPA with the resources needed for either enforcement actions against responsible parties or undertaking cleanup activities on its own. The term *Superfund* is sometimes used interchangeably with CERCLA/SARA. The Superfund tax expired in 1995, and Congress has not reauthorized it. The EPA has reduced funding for the cleanup of abandoned hazardous waste sites and now conducts removal and remedial actions at only very high priority facilities. An attempt to reauthorize the Superfund tax failed in 2004, and although it has been reintroduced several times, it has yet to be passed into law.

CERCLA/SARA is implemented within the framework of the National and Hazardous Substances Pollution Contingency Plan or, more simply, the National Contingency Plan, or NCP. The NCP establishes the procedures and protocols that must be followed by EPA and private parties conducting CERCLA/SARA-type investigations and remedial actions. The NCP dictates the procedures; the actual cleanup is directed by the EPA.

Another important aspect of NCP is that it establishes the National Priorities List, or NPL. This list, also known as the Superfund Site List, includes those places that the EPA has determined represent serious threats to public health and the environment. A site is placed on the NPL if it is appropriate, using such factors as the number of people a release from the facility could impact, the types and conditions of hazardous substances present, and the potential for those substances to contaminate drinking water supplies or the air. Only those sites listed on the NPL qualify for funding of long-term remedial actions under Superfund. States can nominate sites for inclusion on the NPL to obtain money for cleanup, while companies that have facilities nominated for the NPL hotly contest the listing to avoid the stigma and to maintain greater flexibility in planning and implementing a remedial action.

A site is placed on the NPL subsequent to publication in the Federal Register and after a public



review and comment period. The EPA then contacts all companies that may have sent waste to the site for disposal or had an ownership interest in the facility. This list can number in the hundreds of companies, which are called Potentially Responsible Parties (PRPs). Under CERCLA/SARA, PRPs are liable (jointly and severally liable for the contamination on the property. The EPA may recover the full cost of the cleanup from any company that contributed waste or was involved in the ownership or active management of the site, regardless of what percentage of waste or interest the company had. Even if a company contributed 1 percent of the waste at a site, it can be required to pay up to 100 percent of the cleanup. Supporters of this rule contend that it protects the government from being undercompensated if one company cannot pay its share of the cleanup costs. It also makes enforcement proceedings easier because the EPA is not required to decipher how much a PRP contributed to the contamination at a site. Critics of the rule argue that it is unfair to PRPs with minor contributions. It encourages the EPA to find larger companies and has resulted in extensive litigation by PRPs trying to avoid paying for cleanups costs, which can be in the tens of millions of dollars for some sites.

Once the PRPs have been identified, the EPA may elect to negotiate with them to perform the required remedial actions, or EPA may proceed with the cleanup and attempt to recover the Superfund money through a CERCLA/SARA cost recovery action. If successful, the EPA cost recovery actions typically are for three times the amount of the actual cleanup and are intended to provide a strong incentive for PRPs to work together and implement needed remedial actions at the site.

The site investigation process follows steps described in the NCP. The first part of the process is the Remedial Investigation, or RI, which identifies the nature and extent of the contamination. Samples of waste, soil, groundwater, sediment, surface water, building materials, and air are analyzed to determine the locations and concentrations of waste or waste constituents. These data are used in a risk assessment to prioritize remedial actions. Upon completion of the RI, a Feasibility Study, or FS, is carried out. The objective of an FS is to evaluate both short- and long-term remedial options and to select the most appropriate one for the site. Remedial alternatives are compared against a number of criteria including long-term effectiveness, implementability, public acceptability, and cost. Often the RI and FS are done consecutively, and the EPA is presented with a single RI/FS study.

Upon review of the RI/FS, the EPA selects the final remedial action for the site and publishes its decision, along with supporting rationale, in a document called a Record of Decision, or ROD. The ROD summarizes the history of the site, the investigations performed, and the remedial actions considered during the FS. It also describes the public outreach carried out during the process and contains an account of the EPA decision-making process for the remedial alternative. After the ROD is published, the final remedial solution is implemented. If no financially solvent PRPs have been identified for a site, final remediation is dependent upon the availability of funding.

At some sites, a simple removal action is all that is needed to remediate it. In these situations, the site does not have to be added to the NPL for the EPA to commit Superfund monies. These are called limited response actions and generally occur in sites where the value of the remedial action is less than \$2 million.

### Objectives

Recent changes to CERCLA/SARA have created a class of PRPs that may be exempt from cleanup liability. These are innocent owners, purchasers of a property who conducted all appropriate inquiry for pollution when they acquired the site. If contamination is later found on the property, the new owner will not have to clean it up, if they do nothing to make it worse and cooperate fully with regulatory agencies. Similarly, adjacent property owners cannot be held liable for cleanup costs related to contamination that migrated onto their land.

## EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT (EPCRA)

Included as part of the 1986 Superfund Act Reauthorization Amendments (SARA), EPCRA requires certain businesses to submit information about the hazardous chemicals on their property to the EPA. This requirement was mandated to allow public access to information concerning hazardous chemicals in a community and to encourage the development of local emergency response plans. It also provides a strong incentive for businesses to phase out the use of hazardous substances to obviate any reporting requirements.

### Requirements

Local Emergency Planning Committees (LEPC) are named by states to review EPCRA information and develop plans to deal with a release of hazardous materials into the environment. Extremely Hazard-

ous Substances are chemicals covered by EPCRA including those with inherently acute and chronic toxicity, reactivity, or volatility that could cause serious irreversible health effects in the event of an accidental release. If a business stores or uses more than certain threshold quantities of ECRA substances, ranging from a few pounds to more than 500 pounds (227 kg), it must file the appropriate notifications. Reporting threshold quantities for other hazardous chemicals are much higher, ranging up to 10,000 pounds (4,545 kg) for some substances.

The quantities and in-plant locations of the hazardous substances are compiled and reported using either a tier I or a tier II inventory form. Tier I reports provide information on the maximal and average daily amounts of hazardous chemicals in use at the facility. If the LEPC requests additional, chemical-specific information, then a tier II report is filed describing the form of the hazardous substance, its health and physical hazards, and how it is stored and handled. Recently, transmittal of tier I and tier II forms is done electronically in software developed by the EPA so data can be forwarded to LEPCs without the need for extensive reformatting.

Certain facilities also are required to report the release of selected toxic chemicals into the environment. This reporting is not just limited to accidental spills or releases; it also includes those associated with permitted discharges from wastewater treatment plants, shipped to off-site disposal facilities, or emitted to the air through permitted stacks and vents. These releases are reported on a Form R and are available for public review.

### Objectives

EPCRA reporting requirements are viewed as potentially infringing on trade secrets or other types of proprietary manufacturing processes by many companies. LEPCs have antiterrorist concerns over making widely available the location and quantities of Extremely Hazardous Substances at a specific plant. EPCRA, however, has been very effective in alerting communities to risks associated with industrial activity around them and in having businesses reevaluate their need for hazardous chemicals.

### OTHER ENVIRONMENTAL LAWS

Although not as far-reaching or universal as RCRA or CERCLA or NEPA, there are several other supporting pieces of important environmental legislation. These laws, and their associated regulations, have been promulgated to address specific environmental or perceived public health risks that were not being adequately addressed. They include:

- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) was passed in 1947 and amended repeatedly through the 1970s, 1980s, and 1990s. It requires registration of pesticides with the EPA and labeling about use and potential health effects. FIFRA's jurisdiction overlaps with that of the Occupational Safety and Health Administration (OSHA) in worker exposure issues and the Food and Drug Administration in residues on food or other consumer products. Registration applications require the manufacturer to provide extensive toxicological and environmental information about its product and, if approved by EPA, are only valid for a limited time. FIFRA also requires that most pesticides can only be sold to and used by or under the supervision of a certified applicator. Also, EPA has authority to cancel the registration of any pesticide and have it removed from the market if it finds that the product represents an imminent hazard to people or the environment. Unlike many other environmental statutes, FIFRA is almost solely administered by the EPA with very little delegation of authority to the states.
  - Oil Pollution Act (OPA) was passed in 1990, shortly after the *Exxon Valdez* spill. The OPA assigns liability for spills to the owners and operators of vessels or shore facilities, without regard to fault. This means that even if the release was not caused by the actions of the vessel's crew or staff, its owner and operators must pay for cleanup and related damages. Damage includes injury to property, injury to natural resources (birds, fish, etc.), lost revenue or taxes (tourism, fishing, etc.), and loss of public services. OPA limits the liability of a responsible party for removal and cleanup costs to specified amounts, depending upon the size of the vessel involved in a spill. Examples include a \$2 million limit of liability for vessels less than 3,000 tons (2,722 metric tons) or \$10 million for vessels larger than 3,000 tons (2,722 metric tons). For onshore facilities and deepwater ports, the limit of liability is \$350 million. Gross negligence or intentional malfeasance, however, removes those protective liability caps.
- If the cost of the spill exceeds the limit of liability, the responsible party can make a claim to the Oil Spill Liability Trust Fund,

which was established as part of OPA. Funded by a tax on imported oil, the now \$1-billion-plus fund is administered by the U.S. Coast Guard and is used to pay for both emergency response actions and longer-term cleanup activities, including compensation to third parties. OPA requires that all vessels operating within the U.S. territorial waters participate in mandatory drug and alcohol testing programs and that tankers be double hulled by 2015.

- Toxic Substances Control Act (TSCA) was passed in 1976 and amended three times since. TSCA requires manufacturers of chemicals to provide information on the health and environmental effects of their products and chemical mixtures and authorizes the EPA to regulate the formulation, distribution, use, and disposal of these materials. The EPA reviews information on new chemicals before they are manufactured and requires testing of new or modified chemicals that may present a significant risk to human health or the environment. If the EPA finds that the risks of the new or modified substance are not outweighed by their potential benefit in commerce, then they can ban its manufacture and distribution, including import and export of the chemical.

Under TSCA, the EPA compiles and updates an inventory of chemical substances manufactured or used in the United States. This list, known as the TSCA Inventory, contains information on the health and environmental effects of hundreds of thousands of chemical substances and mixtures used for commercial purposes as well as genetically engineered organisms. TSCA also regulates the use of existing chemicals that present a risk to health or the environment. These include asbestos, which was banned in 1989 by TSCA, as well as PCBs.

- Occupational Safety and Health Act was passed in 1970 and established the Occupational Safety and Health Administration (OSHA), which is responsible for safety and health in the workplace. Although not an environmental agency, OSHA regulates worker exposure to many different chemicals that also often are released to the environment. OSHA also sets exposure standards called Permissible Exposure Limits (PELs) for certain chemicals, and they are

used regularly as the basis for environmental and public health risk assessments.

OSHA also regulates companies generating hazardous waste or using hazardous chemicals and requires that they develop a hazardous communication (hazcom) program for their employees. Hazcom describes possible exposure risks and includes container labeling and posting of warning signs in appropriate chemical processing or waste storage areas. The centerpiece of OSHA's hazcom requirement is the Material Safety Data Sheet, or MSDS. This data sheet describes the physical and chemical properties of a substance and includes information on its potential health and environmental risks. The MSDS is intended to alert workers and emergency responders to the precautions and protocols to deal safely with a release of the substance.

*See also* AIR POLLUTANTS AND REGULATION; AIR POLLUTION; BROWNFIELDS; LANDFILL; SAFE DRINKING WATER ACT; SUPERFUND SITES; UNDERGROUND STORAGE TANK.

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**Erika oil spill Brittany, France December 12, 1999** *Water Pollution* Built in 1975, the *Erika* was an oil tanker registered in Malta and owned by Tevere Shipping, a Greek shipping company. It was built at the Kasado Dock Co. in Japan, one of eight similar ships that were intended to be sold as smaller (slightly less than 600 feet, or 183 m, long), inexpensive alternatives to the massive supertankers that were regularly transporting oil from the Middle East to Europe and the Americas. After many years of uneventful service, the useful life of the *Erika* was coming to a close. Almost 30 years old and not very sturdily built, by 1999, the *Erika* was serving the low end of the shipping market. It was cheap to charter and, according to a recent inspection by Registro Italiano Navale e Aeronautico, or the Italian Register of Ships and Aircrafts (RINA), it was still seaworthy.

RINA, a nonprofit organization, was founded in 1861 in Genoa, Italy, and is one of 10 international organizations that issue “class certification” documents. These confirm or validate that the certified vessel has been designed, built, and maintained in accordance with certain maritime standards and can be used for the intended purpose, which, in the case of the *Erika*, was the transport of oil. Certification requires that RINA conducts inspections during a ship’s construction and periodically during its operational life, including routine checks on an annual basis and more comprehensive inspections every five years. Inspection frequency increases as the ship ages. Without RINA or an equivalent certification, the vessel could not obtain insurance; nor would it be allowed to pick up or unload cargo in most ports. In summer 1998, the *Erika* successfully passed its five-year RINA inspection and underwent a major overhaul and repair in dry dock, including an inspection of its structural integrity. Throughout 1999, the aging tanker had been inspected 11 times and in each case had received an acceptable rating.

### THE ACCIDENT AND SPILL

On December 8, 1999, almost 31,000 tons (28,123 metric tons) of no. 2 fuel oil was loaded onto the *Erika* from an oil storage terminal in Dunkirk, the third largest port in France and a vital industrial center. The *Erika* was bound for a power plant owned by Italy’s most important electric utility, Ente Nazionale per l’energia Elettrica (ENEL). The fuel

oil was to be burned to make steam to turn the turbines connected to the generators needed to produce electricity. The oil in the *Erika*’s hold was owned by the charter company, Total Group, the world’s fourth largest oil and gas company. Formed by the merger of Petrofina (a Flemish oil company) and two French oil and chemical companies, Total and Elf Aquitaine, Total Group today is similar in size to Shell, BP, and ExxonMobil Corporations.

After performing its own evaluation of the ship, called a vetting, which primarily is a review and examination of inspection and maintenance records provided by the vessel’s owner and RINA, Total Group was satisfied with their choice to charter the *Erika*. At very low rates, Total Group would be able to deliver its oil safely and inexpensively and make a nice profit on this much-needed wintertime commodity.

Sailing from Dunkirk and into the Bay of Biscay, the *Erika* encountered a major winter storm. Battling 20-foot (6-m) waves and 60-mile-per-hour (96.6-km/h) winds, the ship made slow progress toward Italy. At about 2:00 p.m. on December 11, the ship’s master sent a telex distress signal to CROSS, the Regional Rescue and Surveillance Center, equivalent to the U.S. Coast Guard. CROSS centers manage, direct, and perform rescue efforts as well as control navigation and fishing activities in French waters.

The telex message sent by the *Erika* to CROSS informed them that the ship was listing to starboard by about 10 degrees, gave the position of the vessel, but indicated that the list was under control and that no immediate assistance was required. The crew was attempting to correct the list, or rebalance the ship, by pumping ballast water from one section of the hull to another. The captain later cancelled the distress call and advised CROSS that he would submit a more complete report on the situation at a later time. At around 6:30 that evening, which was a Saturday, the ship captain called Total Group headquarters and left a voicemail message informing them that the weather was too severe to continue on the planned course and that he was turning toward the French coast to seek shelter until the storm dissipated. As the *Erika* sailed within 45 miles (70 km) of Brittany’s Finistère Peninsula, the crew reported that there was a crack in the main decking plates that extended across almost the entire width of the vessel.

At around 6:00 a.m. on Sunday, December 12, the captain issued a second distress call to CROSS, warning that the ship “had very serious structural problems” and requesting that he and his crew be evacuated immediately. When French CROSS and British navy helicopters arrived, they found the *Erika* in two pieces about a quarter-mile (0.4 km) apart.





The stern of the tanker *Erika* sinks after breaking up off the Brittany coast, France, December 13, 1999. (AP Images)

Oil was in the water. Fighting gale-force winds and very rough seas, they winched to safety the 26-person crew from the now separated and drifting wreck.

Twelve days later, on December 24, driven westward by more winter storms, the cargo oil spilled from the *Erika* reached and began to spread along the French Atlantic coastline. Eventually, the oil washed up along a 250-mile (400-km) stretch of beaches between the Finistère and Charente-Maritime, one of the major vacation destinations for European tourists in France. Later estimates concluded that of the almost 34,200 tons (31,000 metric tons) of fuel oil on the *Erika*, about one-third (11,000 tons, or 10,000 metric tons) washed up on the shore.

### CLEANUP AND IMPACT

The impact of this oil spill was severe, despite the efforts of 800 soldiers and countless paid laborers and volunteers to recover the oil and minimize its ecological damage. The carcasses of 21,000 oil-covered, dead, or dying seabirds, mostly guillemots, puffins, gannets, and kittiwakes, were found during the cleanup effort, and Brittany's Society for the Study and Protection of Nature estimated that another

80,000 were likely to die. Once coated with oil, the birds tried to preen, or use their beaks to scrape the hydrocarbon off their feathers. This resulted in ingestion of the oil and their eventual poisoning. Many birds were captured and airlifted to a special cleaning and treatment facility in England but did not survive the trauma or succumbed to hypothermia as the natural, protective oils that coated and insulated their feathers was stripped off, either by the *Erika's* oil or by detergents used to clean them.

Bulldozers, excavators, shovels, and rakes were used to collect 297,600 tons (270,000 metric tons) of oily sand and debris off the beaches. This material was taken to a nearby Total Group oil refinery in Donges, France, for recovery and recycling or disposal. Tourism dropped by 85 percent that year, and the offshore oyster and mussel beds, a source of much-needed revenue for many local residents, were destroyed. Fishery resources were not as exposed to the oil and not significantly impacted. Oil collection and beach restoration continued until midyear 2003, with the last of the oily debris treated at Donges in 2004.

The severe weather minimized the effectiveness of floating oil recovery operations at the offshore

wreck of the *Erika*. Only an estimated 1,100 tons (1,000 metric tons) of oil was recovered by skimmers and booms. The two pieces of the *Erika* continued to drift, and, on December 13 as French authorities attempted to tow the stern section farther out to sea, it sank. The forward section had gone down earlier. Both sections of the ship contained an estimated 12,100 tons (11,000 metric tons) of oil and were now resting on the bottom of the ocean in some 400 feet (122 m) of water just 40 miles (64.4 km) south of the Brittany coastline. Obviously, so much oil so close to one of the most important tourist centers and ecological habitats in France could not be allowed to remain in place. The threat from ongoing leakage was too great. Total Group responded by using recently developed remote robot technology, eventually sealing the hulls and, by September 2000, recovering almost all of the 12,200 tons (11,000 metric tons) of oil from the two derelict pieces of the sunken hulls. The remaining 9,000 gallons (34,070 L) of oil released by the *Erika* when it sank is thought to have been either biodegraded or dispersed within the ocean.

### THE AFTERMATH

Investigations by RINA, Total Group, and the French government generally seem to agree that the probable cause for the *Erika* disaster was that the vessel's internal structural system failed and that this failure probably was related to repairs to the ballast tanks performed in 1997. RINA had inspected and approved these repairs at the time they were being done. As experts appointed by the Dunkirk Commercial Court concluded, "the true condition of the vessel's structures was not consistent with the certification issued by RINA." The report also raised questions as to whether these and other repairs actually were carried out. These same experts further found that the severe weather contributed to the *Erika*'s sinking, but that by themselves, the rough seas and high winds should not have caused the ship to go down.

Liability for damages associated with the sinking, including the cleanup, ecological destruction, loss of the ship and its cargo, and economic impacts from missed tourism, are still being adjudicated. The vessel's owner claims that RINA is to blame and has refused to accept responsibility for the damage the oil spill has caused. RINA admits to some responsibility for the failure of the ship but states that the owner was ultimately responsible for the maintenance and safe operation of the vessel. Total Group has claimed that it could not have known about the poor condition of the vessel and that it relied on

information provided by RINA and the ship's owner during its vetting process.

Total Group has reserved almost \$270 million to pay for the cleanup and settle claims made by injured parties. The International Oil Pollution Compensation (IOPC) fund has settled 5,600 private party claims for almost \$158.4 million and is still in negotiations over another 1,300 claims. IOPC also paid the French government \$53.8 million for the costs of the cleanup and is expected to settle the remaining governmental claims of almost \$200 million. In early 2007, the trial began in a Paris criminal court to determine final responsibility for the spill. Total Group, the owners of the oil, and the *Erika*'s charter company, is accused of pollution and deliberately failing to take the necessary measures to prevent the release of oil from the *Erika*. Fourteen other individuals and corporations, including four that participated in sea rescue and oil recovery operations, also are on trial, accused of similar charges. More than 60 plaintiffs, including the French government and three labor unions, are claiming damages.

In January 2008, a French court convicted the Total Group of maritime pollution and ordered the company and three other parties (RINA, the ship's owner, and the ship's operator) to pay \$285 million in compensation. Ten other defendants, including the ship's captain, were acquitted. The group is currently appealing the verdict.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS; WATER POLLUTION.

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**ethylbenzene** Ethylbenzene is part of the BTEX (benzene, toluene, ethylbenzene, xylene) component of fuel including gasoline, diesel, and jet fuel. Fuel leaks from gas stations or other fuel storage facilities, as well as spills during transportation, are probably the most common point source pollutants to groundwater systems in urban to suburban areas. Exhaust pipe emissions also contain ethylbenzene, providing a significant nonpoint source of pollution in the same areas. Although ethylbenzene may have limited industrial uses, its presence in fuel make it one of the most widespread pollutants. To illustrate how prevalent ethylbenzene is, it has been identified in 731 of the first 1,467 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List), which is among the highest percentages of any hazardous substance. It is largely for this reason that ethylbenzene is rated as the 99th most dangerous contaminant on the 2007 CERCLA Priority List of Hazardous Substances, which includes 275 entries. The properties and health effects of ethylbenzene make up the rest of the reasons for concern.

### PROPERTIES, USE, AND PRODUCTION

Ethylbenzene, also known as ethylbenzol and phenylethane, is an organic compound that is classified as a hydrocarbon. It is naturally occurring in crude oil and coal tar and occurs as a colorless liquid with a strong gasolinelike odor. As an industrial chemical, more than 99 percent of ethylbenzene is used to make the organic compound styrene, which, in turn, is used to make polystyrene and other plastics. The remaining ethylbenzene is used as a solvent for paints, stains, varnish, lacquers, rust preventative, adhesives, inks, and cleaning fluids, as well as in making rubber, dyes, perfumes, degreasers, pharmaceuticals, pesticides, and plastic wrap. Its main use, however, is in gasoline (about 2 percent by weight) and other fuels, as well as in tar and consequently creosote, asphalt, and naphtha-containing compounds. The production of ethylbenzene as an individual compound increased from 6.9 billion pounds (3.1 billion kg) in 1982 to 11.8 billion pounds (5.4 billion kg) in 1993 and more than 12 billion pounds (5.5 billion kg) by 1994.

### ENVIRONMENTAL RELEASE AND FATE

Not only is ethylbenzene widely released into the environment through its presence in fuel and other petroleum products, it has other nonpoint sources including tobacco smoke, wood smoke, incineration, power generation, and any internal combustion

engine. It is released as a point source pollutant from industrial emissions including spills and leaks during storage and transportation and improper disposal. Ethylbenzene is primarily released to air, because it evaporates easily. Even emissions to water and land contribute to the vapor content in the atmosphere. It degrades in air by photochemical reactions with hydroxyl radicals with a half-life rate of 0.5–2 days depending upon physical and chemical conditions. These by-products contribute to smog and may be removed back to the surface by precipitation. If released to surface water, most of the ethylbenzene will evaporate with a removal half-life of 3.1 hours for rapidly flowing water. That which does not evaporate will primarily undergo aerobic biodegradation and chemical reactions, though some may adhere to particles and settle into the sediment. In soil, the remaining ethylbenzene that does not evaporate is relatively mobile in most cases, binding only moderately to most soil particles though more strongly to clay and organic material. Leaching into groundwater is, therefore, common, especially around waste facilities. Once in groundwater, it will degrade in about eight days (10 days in seawater). Breakdown in soil and groundwater is primarily through biodegradation but also through chemical reactions depending upon condition.

The industrial release of non-fuel-related ethylbenzene as reported in the EPA Toxic Release Inventory from 1987 to 1993 was more than 761,000 pounds (345,909 kg), 94 percent of which was to land. The releases were primarily from petroleum refining and as such were far and away most common in Texas, followed distantly by the Virgin Islands, Illinois, Puerto Rico, Virginia, Delaware, New Jersey, New Mexico, Wyoming, and Louisiana. These industrial releases pale in comparison to its release as a component of fuel and in vehicle exhaust.

### HEALTH EFFECTS FROM EXPOSURE

Ethylbenzene is considered to be moderately toxic through both inhalation (the most common route) and ingestion. Acute exposure to ethylbenzene produces throat and eye irritation, excess salivation, tightening of the chest and labored breathing, and central nervous system effects such as fatigue, dizziness, and headache. In high doses, it has been shown to cause pulmonary effects, kidney and liver damage, and death at extreme dosage. Chronic exposure has caused damage to the blood, central nervous system effects, and kidney and liver damage. Ethylbenzene has also been shown to cause reproductive problems including increased incidence of fetal resorption and developmental problems such as



slowed skeletal growth and birth defects. The EPA classifies ethylbenzene in group D, not classifiable as to its potential as a human carcinogen. Several studies, however, have shown an increased incidence of kidney and testicular cancer in rats and lung, bronchial, thyroid gland, pituitary gland, and liver cancer to varying degrees in mice as the result of exposure to ethylbenzene.

### REGULATIONS ON HUMAN EXPOSURE

Worker and public exposure to ethylbenzene is regulated by several federal agencies; however, almost everyone is exposed to it in some form. The EPA limits ethylbenzene in drinking water to a maximum of 0.7 parts per million (ppm) under the Safe Drinking Water Act. They recommend a maximal exposure of 20 ppm for any one-day period, and for any longer periods it should not exceed 3 ppm. They also require the reporting of any spill of ethylbenzene of 1,000 pounds (454 kg) or more to the National Response Center in Washington, D.C. The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) of 1 ppm of ethylbenzene in workplace air over an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set their exposure limit (REL) to the same level as OSHA but over a 10-hour day. They further set a short-term exposure limit (STEL) at 125 ppm for any 15-minute period and an immediately dangerous to life and health (IDLH) limit at 800 ppm.

See also BENZENE; SUPERFUND SITES; TOLUENE; VOLATILE ORGANIC COMPOUNDS; XYLENE.

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**eutrophication** Virtually all surface water bodies in the United States are undergoing some degree of the complex process of eutrophication. In urban and agricultural areas, eutrophication is rampant and has radically impacted the ecology of water bodies. Many communities have taken steps to reduce the effects, but it is a losing battle and some of the methods risk further environmental degradation. More recently, eutrophication has begun to invade our coastal marine waters as well in the form of "dead zones." These features are more of a threat to the environment and even threaten human survival.

### THE PROCESS OF EUTROPHICATION

The basic cause of this eutrophication is overfertilization—the overabundance of nutrients in a water body that causes the algae and vegetation in the water to bloom. Reproduction, growth, and survival of individuals are greatly enhanced, and the water body turns green with growth. Such productivity might appear desirable as it provides more food and actually consumes carbon dioxide. These aquatic species, however, are short-lived, and the water soon becomes choked with plant mass. Bacteria, in turn, flourish with the abundance of food for them. The problem is that these bacteria consume oxygen in the water. As a result, hypoxic conditions develop in the water body. Many of the other organisms that inhabit the water body depend on oxygen in the water for their survival. They are either killed by the conditions or driven off, depending upon their mobility and whether the water body is closed or open. As a result, the body will have a reduced biodiversity, especially with regard to fish and aquatic invertebrates and in extreme conditions may become "dead" with respect to all animals. The loss of these organisms is progressive because different species have different tolerances for oxygen in the water. There are even some organisms such as jellyfish that are relatively unaffected by hypoxic conditions and can survive, even prosper, in water with low oxygen content.



### CAUSES OF EUTROPHICATION

Certainly, eutrophication is a process that occurs commonly in nature. Heavy rain or quick spring thaws can sweep nutrients from the terrestrial surface into a water body. A small response takes place, but natural processes regulate themselves relatively well in all but the most extreme of cases. The real problem with eutrophication results from anthropogenic input of nutrients into surface water.

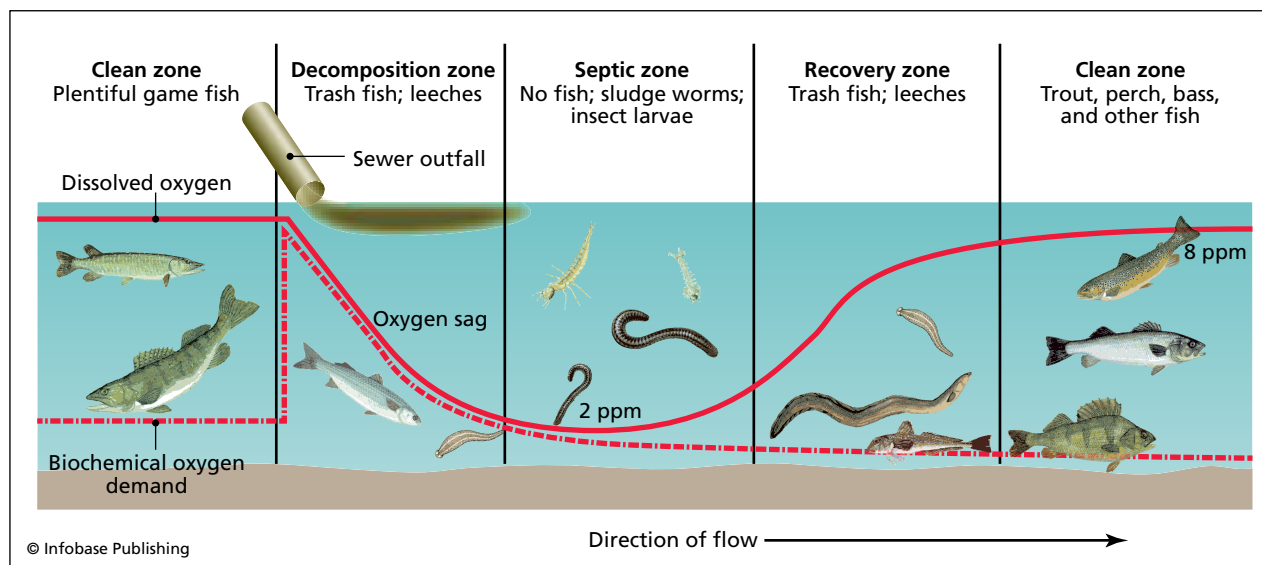
The major cause of eutrophication is the overuse of fertilizers. By far, the chief source for the vast majority of the volume applied to surface water is agricultural. Although natural fertilizers such as manure can cause eutrophication, the greatest source is chemical fertilizers. As the population increases, there are greater demands on farmers to produce greater amounts of food, and the overuse of fertilizers can become rampant. There is no problem as long as the fertilizer remains on the field, but any rainstorm or even just a watering of the plants washes some of it into streams, ponds, and other surface water bodies. Small amounts of fertilizer can be absorbed into local ecological systems, but large

quantities overwhelm them, and the excess continues into ever larger streams, rivers, and lakes. It is by this process that eutrophication becomes epidemic.

For most of agricultural history, any excess nutrients that continued through river systems and emptied into a receiving ocean basin were quickly absorbed into the vast marine ecosystem. In the 1960s, however, a zone of eutrophication developed in the large Black Sea in the Soviet Union (USSR) as the result of heavy agricultural activity in the area. It was still thought by most that such an occurrence could only happen in a restricted body of water such as the Black Sea and under unusual conditions of heavy use of fertilizers. These hypoxic zones in marine waters were named dead zones because of the lack of marine organisms. These dead zones began to develop in many areas around the world where a major river flowed through an agricultural area. At the mouth of the Mississippi River, the dead zone in the Gulf of Mexico is the size of the state of New Jersey and one of the largest. By 2006, some 200 dead zones had been identified around the world.



Algae bloom off Coquina Beach, Florida, 2006 (AP Images)



**Cartoon diagram illustrating how eutrophication takes place in a stream. The left side shows a healthy stream with diverse fauna, abundant dissolved oxygen, and low biochemical oxygen demand (BOD). Input of sewage increases BOD, thereby reducing dissolved oxygen to conditions that can only support a poor and undesirable fauna. It takes quite a bit of natural attenuation of the sewage to restore the stream to healthy conditions. Input of fertilizers has the same effect.**

Agricultural fertilizer is not the only source for eutrophication. The quest for the perfect lawn in the suburbs also requires a heavy treatment of fertilizer. During precipitation events, surface runoff carries the excess nutrients from the lawns to storm drains and finally into streams and rivers or directly into the ocean, in the case of coastal communities. Eutrophication of bays, estuaries, and even the ocean is increasing in many areas of the United States. One of the better-developed dead zones occurs in the Chesapeake Bay of Maryland. There is some agricultural component to the nutrients, but coastal development has also been identified as a contributor. This coastal eutrophication is drastically reducing the productivity of coastal waters and may have dire consequences for the burgeoning human population on Earth.

Another source of nutrients in these coastal settings is overflow of septic systems. This was also the major cause of eutrophication of lakes and ponds in populated urban and suburban areas in the past. It may still be the case in some areas, but the building of new leak-proof, high-capacity sewer systems has reduced septic overflow in general. This issue was even addressed in a legislative manner in the 1970s to some degree. Clothes washing detergent used to contain phosphates. These phosphates had a strongly negative effect on ponds and streams to the point where they were restricted and banned from detergents as the result of public pressure and atten-

tion by the government (Congressional Report HR 92-918 March 15, 1972).

Air pollution fallout and washout by precipitation are other sources of eutrophication. Particulate can contain a significant amount of nitrogen compounds, and one of the six criteria air pollutants is nitrogen oxides. In the natural environment, these react to form nitrate, which is a strong fertilizer. As a result of this and other factors, there is a large diffuse halo of eutrophication in the waters around several cities that adds to the other factors.

### CONTROLS ON EUTROPHICATION

Besides the removal of phosphates from laundry detergent and even though eutrophication is globally recognized as a major environmental problem, the only controls that have been extended to eutrophication have been incidental. There are regulations on septic systems and sewer capacity and function that curb eutrophication but only as a collateral effect of controlling potential disease from poor sewage management. Air pollution controls and regulations attempt to limit the amount of nitrogen oxides in the air to control acid rain and tropospheric ozone with no thought to controlling eutrophication. The reality is that eutrophication is a widely recognized problem with dire consequences that threaten the very survival of humankind, and yet very little is being done about it.

See also AIR POLLUTION; DEAD ZONE; NO<sub>x</sub>; PHOSPHORUS; SEWAGE TREATMENT PLANTS.

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**ex situ remediation of contaminated groundwater** Technologies related to the remediation of groundwater can be divided into those that require groundwater be extracted and brought to the surface (ex situ) and those that operate within the subsurface (in situ). Each has its advantages and disadvantages, and the selection of one technology versus another is largely dependent on such factors as contaminant type, site physiographic conditions, remedial program objectives, and costs. In this section, nine common ex situ approaches for the cleanup of contaminated groundwater are described.

#### **METHODS TO ESTABLISH HYDRAULIC CONTROL**

Groundwater, as does the surface water in streams and rivers, moves in response to changes in hydrostatic pressure. These changes can be driven by differences in recharge or infiltration rates, a variety of subsurface features, or even withdrawal of groundwater in other areas. For an ex situ remedial system to be effective, groundwater must be collected at a fairly predictable and steady rate, but the natural forces that influence groundwater movement are

often not reliable and steady. A number of recovery methods, therefore, are used to capture or divert contaminated groundwater into collection devices for transport to an ex situ treatment facility. The most commonly used ones include pump and treat; French drains or interceptor trenches; slurry walls; and phytohydraulics.

#### **Pump and Treat**

When groundwater is withdrawn from an aquifer, or water-bearing zone, by a pump installed in a well, it causes a lowering of the water table in the area around the well. The extent of this artificially lowered water table, if viewed in cross section, is called the pumping well's cone of depression and is dependent on such factors as:

1. pumping rate, or the amount of groundwater being withdrawn over time;
2. the amount of water the subsurface sediments hold, or specific capacity; and
3. the rate at which new groundwater can move through the subsurface to replace the groundwater that has been pumped out, or the transmissivity of the sediments.

If wells are aligned in a pattern such that their cones of depression overlap, they create an obstruction or barricade through which groundwater cannot pass. This method, called pump and treat, is a system of wells aligned to form a hydraulic barrier to collect contaminated groundwater for subsequent treatment and to prevent its migration to uncontaminated areas.

A significant shortcoming of pump and treat systems is a phenomenon called rebound. As the cone of depression forms, it draws down the water table and residual contamination may remain adsorbed to soil in this now unsaturated zone. At many sites, this area near the former top of the water table may be the most severely impacted. As contaminants are removed from the aquifer, and monitoring indicates that cleanup goals have been met, the pump and treat system is turned off. The water tables rise to their original (preremedial) levels and become recontaminated by constituents left untreated in the former cone of depression. When this occurs, pump and treat systems are operated in pulse mode, which means they are turned off and on repeatedly in an attempt to flush out the contaminants remaining in the cone of depression. This phenomenon can result in the need to operate a pump and treat system for many years, sometimes decades, as contaminants

stuck to the soil are slowly flushed off by the periodic rise and fall of the water table. In many cases, pump and treat systems are used only when other methods will not be as protective of public health, such as when a contaminant plume is moving toward wells that provide potable water to a large number of people or a municipality.

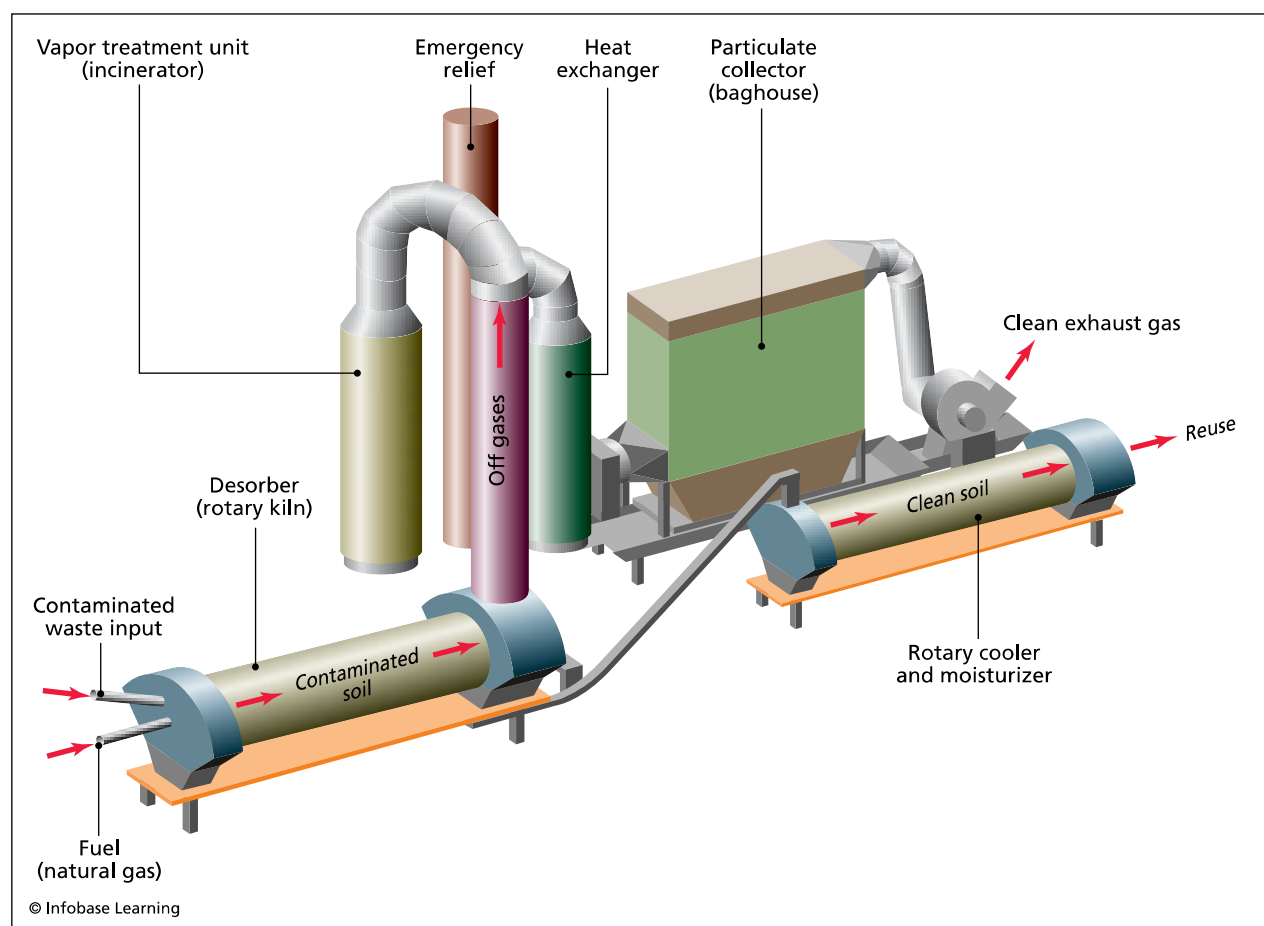
### French Drains

If the groundwater table is near the surface (usually within 20 feet, or 6.1 m) and is present in a soil with a relatively low permeability or hydraulic conductivity, another way to capture it is with a French drain, or interceptor trench. French drains have been used for years by homeowners and landscapers to remove excess water from low areas and other places where the soil tends to become saturated. Essentially they are trenches excavated deep enough to intersect the groundwater. The trench is filled with gravel and topped by a layer of sand. Usually, modern French drain designs include a perforated drainpipe to aid in water collection.

French drains are low cost and easy to install, they do not require electricity, and they can operate effectively for years with relatively little maintenance. They also can be covered over with asphalt or landscaping, making them easy to incorporate into site redevelopment plans. The French drain or drains are tied to a sump where the groundwater is collected and then pumped to a treatment system. This collection sump must be “intrinsically safe,” or fire and explosion resistant, if the groundwater being collected contains contaminants with explosive or highly flammable compounds.

### Slurry Walls

Also called diaphragm walls or cutoff walls, slurry walls are subsurface barriers consisting of vertically excavated trenches filled with clay slurry. The slurry, usually a mixture of bentonite (a type of clay that expands when wet), Portland cement, coal ash, and water, prevents the trench from collapsing during excavation and helps to slow groundwater flow. As the trench is deepened and keyed into or connected



**Diagram of a low-temperature thermal desorption system in which contaminated soil is fed into a rotary kiln and cooked at relatively low temperatures to vaporize and treat pollutants in several gas and particulate remediation systems.**



to a less permeable subsurface layer or even bedrock, assuming it has the right characteristics, the excavated soil is mixed with more bentonite and returned to the trench, where it hardens, creating an underground dam. As added protection, a layer of plastic is sometimes draped across the downgradient side of the trench to slow groundwater flow further or even prevent the migration of vapors that may be emanating from the contaminated groundwater. Slurry walls can be installed at depths up to 100 feet (30 m) and are generally two to four feet (0.6 to 1.2 m) thick.

### **Phytohdraulics**

Certain plants can be used to influence and, in certain settings, actually control the flow of groundwater. As a plant's roots penetrate the aquifer, they withdraw water to support their biological activities (growth, creation of cell mass, etc.). Phreatophytes are deep-rooting plants or trees that use groundwater as their main source of moisture. *Phreato* is from a Greek word that means "well or spring." Common examples of phreatophytes are the tamarisk (salt cedar) and willow. The ability of phreatophytes to withdraw large quantities of groundwater is well documented. Mature poplar trees use 25–50 gallons (95–190 L) of water per day, cottonwoods 50–350 gallons (190–1,323 L) per day. Willows are enormous water consumers, taking in and transpiring up to 1,300 gallons (4,914 L) per day; that is why they tend to grow in areas where the soil is saturated all year such as swamps and marshes. This uptake, consumption, and eventual transpiration of groundwater can help contain or reduce the migration of contaminants. Although they are very dependent on the type of vegetation, climate and growing season, soil type, and depth to water, the effective rooting depth can be as much as 30 feet (9.2 m) below the surface.

Phytohdraulics has been used in vegetated landfill caps and covers to reduce infiltration of precipitation and snowmelt and therefore minimize the amount of leachate production. The presence of vegetation also helps stabilize the soil and reduce erosion. If used in this way, the selected plants need to have shallow roots so they do not breach the cap or cover and penetrate the waste.

Another use of phytohdraulics is in the construction of buffer strips and riparian corridors. Buffer strips are planted downgradient of the contaminant source to intersect the contaminated plume in groundwater. In addition to helping to control the flow of groundwater, buffer strips offer an opportunity for the selected plants to degrade the contaminants in the groundwater through phytore-

mediation. If buffer strips or filter strips are planted along streams or drainage ditches, they are called riparian corridors and are used to control runoff of pesticides, sediment, and fertilizers from agricultural fields.

## **EX SITU REMEDIATION TECHNOLOGIES**

All of the ex situ technologies described have a number of common characteristics. Each requires a way to capture or control the subsurface migration or flow and recover the contaminated groundwater. In addition, each ex situ technology involves the use of an aboveground treatment facility or plant, which can sometimes be very expensive to build and operate. Finally, ex situ technologies have to include a way to manage the groundwater once it is recovered and treated. This can be done either by discharging it to a surface water body, reinjecting it into the subsurface, or using it in an industrial or commercial application such as cooling for a furnace or air conditioning system. The main advantage of these technologies is that the remedial process can be vigilantly monitored and controlled. The contaminated groundwater is delivered to a treatment plant that has been carefully engineered and is operated by trained and licensed professionals and been permitted by either federal or state regulatory agencies.

### **Air Stripping**

Air stripping is a process whereby recovered groundwater is exposed to or mixed with large quantities of air, causing separation of volatile organic compounds (VOCs) that may be dissolved in the groundwater. This partitioning process takes place because the VOCs have a low octanol-water partition coefficient ( $K_{OW}$ ), or ratio of the concentration of a chemical in octanol and water. The coefficient is measured in the laboratory and given at equilibrium and for a specified temperature. Contaminants with low  $K_{OW}$  are easily partitioned or stripped from the groundwater. Those with high  $K_{OW}$  must be remediated by using another approach. Contaminants such as heavy metals, polychlorinated biphenyls (PCBs), and pesticides cannot be treated by air stripping.

Air strippers spray the contaminated water down a column or stack as air is blown up through it. Inside the column is a packing material, usually plastic or metal baffles, that act to slow the downward flow of water and increase its contact time with the air. The separated VOC vapors are collected at the top of the column and either burned, run through a carbon filter, or distilled and collected for later disposal. The treated groundwater flows out the bottom

of the column and is either returned to the aquifer, or water bearing zone, to flush out additional contaminants or discharged to a sewer or surface water body. Properly designed, air strippers are effective at removing 99 percent of the VOCs from groundwater. The technology is relatively simple, and once the system is operating, it usually is only shut down for routine maintenance or cleaning or changing of the packing material. Electrical usage and operation of air blowers, however, are high, and the packing material is susceptible to fouling (calcium/magnesium scaling or growth of microorganisms). Treatment costs for collected VOCs are often expensive and can add significantly to overall system operation and maintenance expenses.

Collected groundwater usually is pumped to a holding tank, where silt and other debris can be settled out or separated pollutant can be skimmed off or collected. A holding tank also allows contaminated groundwater to be fed into the air stripper at a constant rate. This helps ensure efficient system operation and reliable treatment. Types of air strippers include structured and random packed towers, sieve and diffused chamber trays, and diffuse aerators.

### Bioreactors

Another way to treat contaminated groundwater that has been pumped out of an aquifer, or water-bearing zone, is through the use of a bioreactor. In a bioreactor, microorganisms are allowed to mix or have contact with groundwater and degrade the contaminants by using them as a source of energy. Air and nutrients are added to the groundwater to encourage and sustain microorganism growth. Bacteria are the primary microorganisms responsible for destroying the contamination. Protozoa and rotifers are used to scavenge stray bacteria that try to leave the system.

Bioreactors work only when the contaminants dissolved in the groundwater can be useful as an energy source for the microorganisms. The contaminants must contain carbon that the bacteria can consume relatively easily. They work best for petroleum hydrocarbons and some types of chlorinated solvents. Bioreactors cannot easily treat groundwater with such contaminants as heavy metals, radionuclides, and complex organic chemicals such as pesticides and PCBs. There are two basic types of bioreactors: attached (fixed film) or suspended biological systems.

In attached, or fixed film, bioreactors, an inert medium or structure is provided for the growth of the bacteria. As the contaminated groundwater flows through or across the medium, the bacteria

attack the contaminants, breaking down the organic chemicals to use the carbon as an energy source. The microbial population is derived from natural selection within the reactor or can be borrowed from another bioreactor. As the bacteria grow, they slough or fall off and settle to the bottom of the chamber and are removed during routine maintenance. A trickling filter, where the water is distributed over the top of the growth medium, is a type of fixed-film bioreactor. Eventually, with most of the contaminants removed, the groundwater is sent to a clarifier, where any remaining particulate settles. The water then is tested and discharged.

Suspended growth systems use an open chamber and stirring paddles to mix the microorganisms with the contaminated groundwater. As individual bacteria grow by feeding off the carbon contained in the oil or solvents as their energy or food source, they clump together in a process called flocculation. As the biological floc grows, it becomes heavier and sinks to the bottom of the tank, forming sludge. This sludge layer is periodically removed or sometimes reused in the treatment process. Treated groundwater is sent to a clarifier and then either discharged or recirculated through the buried waste. Some suspended growth systems add minute particles of sand grains, bits of coal or carbon, even chemical gels that bacteria can attach to while they float in the tank. These types of systems are called fluidized bed reactors.

Both types of bioreactors can be combined into a single system called a rotating biological contactor, or RBC. In this system, microorganisms are established on a series of disks mounted on a common shaft or axle. These disks are rotated slowly to move into and out of the contaminated water. As the bacteria grow, they fall off the disk but are kept in suspension by the rotation of the disks to aid in the treatment of groundwater present in the chamber. As groundwater is cleaned, it flows to a clarifier for testing and discharge or waste mass infiltration. Bacterial sludge is removed as necessary from the bottom of the RBC.

Bioreactors are most effective when designed to treat large volumes of contaminated groundwater over long periods. They are especially useful if the contaminant must be destroyed and not simply transferred to another medium as occurs during air stripping. Bioreactors also have limitations. They are difficult to balance, and the microbial populations can be killed off if contaminant concentrations are too high or if nondegrading microorganisms dominate. Low air temperatures can interfere with system performance, and the residual biomass that occurs as the sludge that accumulates in the bottom of the

tank may require special or additional treatment prior to its disposal.

### **PRECIPITATION OF POLLUTANTS**

The treatment technologies described are those effective at removing dissolved organic compounds from groundwater. For metals and radionuclides present in groundwater, the process is more complex. Metals dissolved in groundwater usually occur as soluble salts including nitrates, chlorides, and sulfates such as silver nitrate, barium sulfate, or mercury chloride, among others. The objective of a precipitation treatment process is to convert the soluble metal salt into an insoluble salt that can then be physically removed by filtering or settling from treated water.

Hydroxide precipitation is the most common way of removing metals from wastewater. Hydroxide is a compound that contains an oxide joined with water. To form hydroxides and, thus, cause metals dissolved in groundwater to precipitate is a four- or five-step process.

#### **Step 1: Pretreatment**

Prior to metal precipitation, pretreatment processes sometimes are used to remove or manage substances that may interfere with hydroxide precipitation. For example, groundwater may need to be disinfected to destroy excess bacteria that could cause fouling inside the pipes and tanks of the treatment system. In other cases, precipitation aids such as ferrous sulfate and sodium hydrosulfite are added to condition the water and to help remove dissolved metals from solution. However, this tends to generate significant amounts of waste sludge that must be collected and managed. Calcium chloride and aluminum sulfate are used during a pretreatment step as conditioning agents when fluoride, phosphate, silicates, or emulsified oil needs to be removed from an effluent stream (wastewater).

#### **Step 2: Precipitation**

In precipitation metals dissolved in groundwater are made insoluble, usually as metal hydroxides. Adding alkali treatment chemicals to the water most frequently accomplishes this. Alkalis are soluble salts that are capable of neutralizing acid. They consist mainly of calcium, sodium, or potassium. The two alkalis that commonly are used for hydroxide precipitation are sodium hydroxide (also called caustic soda or just caustic) and calcium hydroxide or hydrated lime ( $\text{Ca}(\text{OH})_2$ , or more simply lime). Other typically used alkalis are magnesium hydroxide, calcium chloride, sodium carbonate, and sodium bicarbonate. Each alkali has advantages and disadvantages. For

example, of the two most common alkalis, hydrated lime is less expensive than caustic soda. Also, the metal hydroxide precipitants produced by using lime have much faster settling rates. Lime, however, takes longer to react than caustic soda and requires a more complicated feeder system. More importantly, lime generates a much higher amount of waste sludge.

The metal precipitation process begins by adding enough alkali material to raise the pH of the water to between 8.5 and 10.0. This is done in a tank called a neutralizer. Each metal hydroxide has a characteristic solubility that is dependent on pH. If the wastewater contains more than one metal, it becomes necessary to compromise among them in establishing a specific pH goal. Driving that compromise is the need to ensure treatment for the most environmentally damaging metal that may be present. Zinc, little more than a nuisance compound, is removed at a pH of 9, but the more dangerous cadmium requires a pH of 11. In this case, the higher pH would be the target level for the process.

The residence, or length of time the groundwater has contact with the alkali, depends upon the chemistry. Assuming good mixing, a minimum of 15 minutes residence is required if sodium hydroxide is used as the alkali. With lime, a minimum of 30 minutes is needed. The amount of metal that remains in solution after pH adjustment depends on the pH set point, the amount and types of metals in the groundwater, and the presence of any compounds that interfere with precipitation.

#### **Step 3: Flocculation**

The precipitated metal initially forms into a colloidal-particle material that has a soft, jellylike appearance. To remove the material from the water, nearly every metal treatment system uses chemical additives to encourage the precipitated metal colloids to join. In this process, called flocculation, chemicals are added so that floating colloids of precipitated metals develop into more solid, fast-settling particles that can be separated from the water. Flocculants commonly used are such inorganic compounds as alum and ferrous sulfate as well as a wide variety of commercially developed organic polyelectrolytes. These are water-soluble chemicals that adhere to the surface of the colloidal particles and discharge the electrical charges present on them to enable flocculation to occur. Organic polyelectrolytes are more efficient in promoting flocculation but are expensive and have to be tailored to the chemistry of the wastewater.

#### **Step 4: Clarification**

Removal of solids by gravity settling, called clarification, is the most typical way to separate insoluble

precipitated metals from treated groundwater before it is returned to the environment. Clarification is a fairly simple process that uses the difference in density between the flocculent-precipitated metals and water.

Clarifiers are circular tanks where treated groundwater is sent from the equalizer for the removal and eventual collection of the floating, precipitated metals. The water enters either the center or the side of the tank. The bottoms of some clarifiers are tilted toward the center of the tank, forming an inverted cone. In these types of tanks, sludge is usually collected in a hopper near the center of the tank base. Other clarifiers use mechanical sludge rakes and surface skimming to move sludge gently into collection sumps.

It is very important to remove most of the flocculent-precipitated metals, also called suspended solids, from the treated water. Suspended solids cloud the water, making it aesthetically unappealing, and may interfere with biological activities in the surface water where it is discharged. In addition, bacteria can attach to or use the suspended solids as hosts or growth media and increase the risk of disease transmission. Finally, the metal or metals removed from the groundwater can redissolve and contaminate the receiving stream. A well-designed and efficiently operated clarifier can treat the waste stream to remove all but 5–10 mcg/L of suspended solids.

### Step 5: Polishing

Clarification is the simplest part of the wastewater treatment process, but it also is the part that is most subject to problems. Regulatory agencies place strict limits on the amounts of suspended solids in discharged wastewater. Frequently, excess suspended solids in the treated water, caused by changes in wastewater characteristics or inefficient plant operation, make compliance with strict pollutant guidelines difficult. Therefore, many treatment facilities use a polishing filter to remove residual suspended solids that may escape the clarifier. Types of polishing filters include sand beds, mixed-media filters, and membrane filters.

Sand beds, also called granular media polishing filters, remove suspended solids from wastewater in the 5–50-mcg/L concentration range. These units typically contain graded sand or a mixture of inert particles such as garnet, pulverized coal, or silica. Similarly to the sand filters used in many swimming pools, suspended solids present in the wastewater are removed by straining. Periodically, the sand beds need to be “backwashed,” or flushed with air or water, to remove the collected solids.

Multimedia filters consist of two or more particle types that have both different grain size and differ-

ent densities. In a three-part multimedia filter, particles with the smallest grain size are also the densest, commonly garnet (density 4.5 g/cm<sup>3</sup>) at a particle size of 0.008–0.016 inch (0.2–0.4 mm). The midsize particles are 0.02 inch (0.5 mm) and an average density of 2.65 g/cm<sup>3</sup>, and the largest particles are 0.04 inch (1.0 mm) and the lightest (typically anthracite) with a density of 1.6 g/cm<sup>3</sup>. If thoroughly mixed and allowed to settle slowly, the multimedia bed grades itself according to the density of the material. The smallest particles will be on the bottom and the largest particles on top. When the wastewater flows from top to bottom, the bigger suspended solids are removed in the upper layers of the filter and the smaller suspended solids near the bottom. This filter also needs to be backwashed in a manner similar to that used for sand beds.

Membrane filtration is one of the most sophisticated and expensive polishing technologies and is most commonly used by metal plating and printed circuit board manufacturing companies as a pretreatment step prior to discharge of wastewater to a sanitary sewer system. Membranes are simply filters that separate, on a molecular level, the components of a mixture on the basis of their size. To do so, the wastewater or concentrate is passed, under pressure, across the semipermeable membrane, and those particles smaller than the pore spaces in the membrane pass through. The membranes can be made out of ceramics, special metal alloys, or even bundled carbon fibers.

Precipitation processes are effective and commonly used to clean metal-contaminated groundwater but have some limitations. Certain organic compounds such as ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetate (NTA) can act as chelating agents, making it difficult to precipitate the metals unless additional treatment chemicals are added to the wastewater. This may significantly increase treatment costs and the amount of sludge generated by the process. The precipitation/clarification process cannot remove suspended solids below concentrations of approximately 5–10 mg/L unless polishing filtration is used. The suspended solids remaining in the wastewater contain metals that can limit the ability of the system to meet regulatory standards. The solubility of metals is dependent on pH. Therefore, a compromise must be made during system operation to ensure that the most environmentally damaging metals are removed from multimetal-contaminated wastewater. This compromise may also limit the overall ability of the system to achieve water quality standards and require multiple treatment steps. Finally, some metal hydroxide sludge may be so concentrated



that it exhibits characteristics of hazardous waste. Indeed, the U.S. Environmental Protection Agency (EPA) has classified sludge from the treatment of electroplating wastewater as hazardous. Such sludge must be specially managed, handled, transported, and recycled or disposed of, at greatly increased operating costs.

### GRANULATED ACTIVATED CARBON (GAC)

Carbon is an essential element for the environmental scientist, not just because it serves as the basis for all life on the planet, but because it has the rare ability to attract and hold, or adsorb, a wide variety of common environmental contaminants. Adsorption is the physical attraction and adherence of gas or liquid (vapor) molecules onto the surface of a solid. Safe, inert, easy to handle, and relatively inexpensive, activated carbon is widely recognized as the most effective way to treat groundwater containing organic solvents as well as certain metals. Activated carbon is produced or manufactured in three steps.

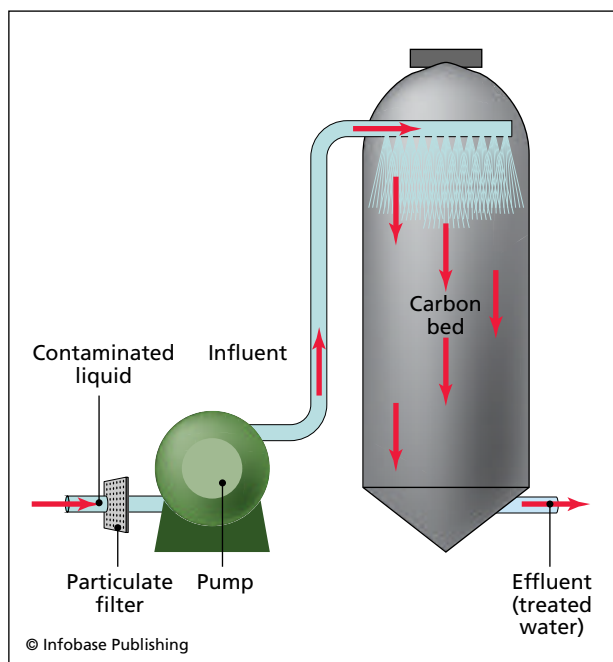
The first step, called carbonization, is to select the raw material, which can be almost any carbonaceous substance, coal, sawdust, or any plant matter. This material is then slowly heated in the absence of air and becomes a charcoal-like highly porous adsorbent material. The choice of the raw material influences the pore structure, particle size, void space, and sur-

face area of the carbon that is eventually produced. The next step, called dehydration, is usually accomplished during carbonization, as the raw material is heated. Once most of the water has been removed from the raw material, it is ready for activation. This process is intended to expand or open up the pore spaces of the raw material and greatly increase its ability to adsorb. There are two types of activation processes, chemical activation and steam activation.

In chemical activation, which is usually used with peat and wood-based raw materials, the carbon is impregnated with a strong dehydrating agent, typically phosphoric acid ( $P_2O_5$ ) or zinc chloride ( $ZnCl_2$ ), and heated to 570–930°F (500–800°C). The resultant “activated” carbon is washed, dried, and ground to powder. Chemical activation produces carbon with a very open pore structure, ideal for the adsorption of large molecules. Steam activation, generally used with coal and coconut shells, occurs when the carbon source is heated to 1,500–2,000°F (800–1,100°C) in the presence of steam. Carbon produced by steam activation exhibits a fine pore structure, very useful for the adsorption of contaminants from both liquids and vapors. The resultant activated carbon is graded, screened, and dedusted. When used for treatment of contaminated groundwater, activated carbon, also called activated charcoal or granular activated carbon (GAC), can be purchased in block, granulated, or powdered form.

Once it is activated, the carbon’s internal surface area dramatically increases to 10,200–12,400 square feet (950–1,150 m<sup>2</sup>) per gram. This means that one pound (0.45 kg) of activated carbon has a surface area of 60–150 acres (24–60 ha). This enormous surface area per unit of GAC is where the adsorbed gases and vapors are held and the adsorption of carbon takes place. If a molecule of organic solvent (trichloroethylene [TCE], for example) has contact with the surface of an activated carbon particle, the unbalanced electrical forces on and within the carbon particle cause the TCE molecule to move down into the smaller pores of the carbon particle. It stops when either the electrical forces become balanced or it is physically blocked.

Treatment systems using GAC are relatively simple to design, can be quickly installed, and are easy to operate. Contaminated groundwater is pumped to a settling tank or through a particulate filter to remove sand, grit, or other large particles that may clog or foul the GAC bed. Once filtered, the wastewater is directed to a carbon bed, usually a cylindrical tank filled with carbon. The contaminated groundwater flows down and through the tank, and the carbon removes the TCE and other contaminants. Treated water is tested to make sure it meets



**Diagram of carbon treatment system for contaminated groundwater. Wastewater enters the system from the left and treated water exits from the right.**

permit or discharge concentrations for the contamination and is released to either a sanitary sewer or a surface water body.

Despite GAC's enormous surface area, eventually it becomes saturated with adsorbed molecules. When this happens, contaminant breakthrough occurs, and the contaminants in the water leaving the carbon tank no longer meet required discharge quality. The GAC is considered "spent" and must be removed for regeneration. The spent GAC is physically transported to a separate facility, where it is heated to 1,500–1,700°F (820–930°C). This process clears about 90–95 percent of the pores. Off-gases from the regeneration process are collected and treated and the carbon is returned to service. How often any given GAC system can operate between regeneration events depends on the strength of the contaminated water and the strictness of the limits for the discharged water.

GAC is not the most efficient way to treat wastewater with high amounts of suspended solids (>50 mg/L) and oil and grease (>10 mg/L) because of fouling problems. Multiple contaminants also can affect system performance, as some contaminants are adsorbed and others not. Finally, system costs can be high compared to those of other technologies if GAC is used as the primary treatment mechanism. Regeneration of carbon is expensive, and eventually the carbon requires proper disposal. GAC is used most commonly as a polishing step after treatment by a bioreactor or air stripping to remove the final residual concentrations of contaminants before treated groundwater is discharged.

Although GAC is the most common adsorbent, there are other natural and synthetic adsorbents used in groundwater treatment systems. These include the following:

#### **Activated Alumina (AA)**

A filter is made by processing aluminum ore to make it porous and therefore highly adsorptive. AA removes fluoride, arsenic, and selenium, but it requires periodic flushing with a special chemical such as alum or acid in order to remain effective.

#### **Forage Sponge**

Forage sponge is a cellulose sponge that is coated with an amine polymer that absorbs certain types of dissolved heavy metals. The polymer can be designed to attract heavy metals in both cationic (positively charged) and anionic (negatively charged) states.

#### **Lignin Adsorption/Sorptive Clay**

These clays are used to treat wastewater contaminated with organics, inorganic compounds, and

heavy metals. The contamination is attracted and held on the adsorptive surface of the clay.

#### **Synthetic Resins**

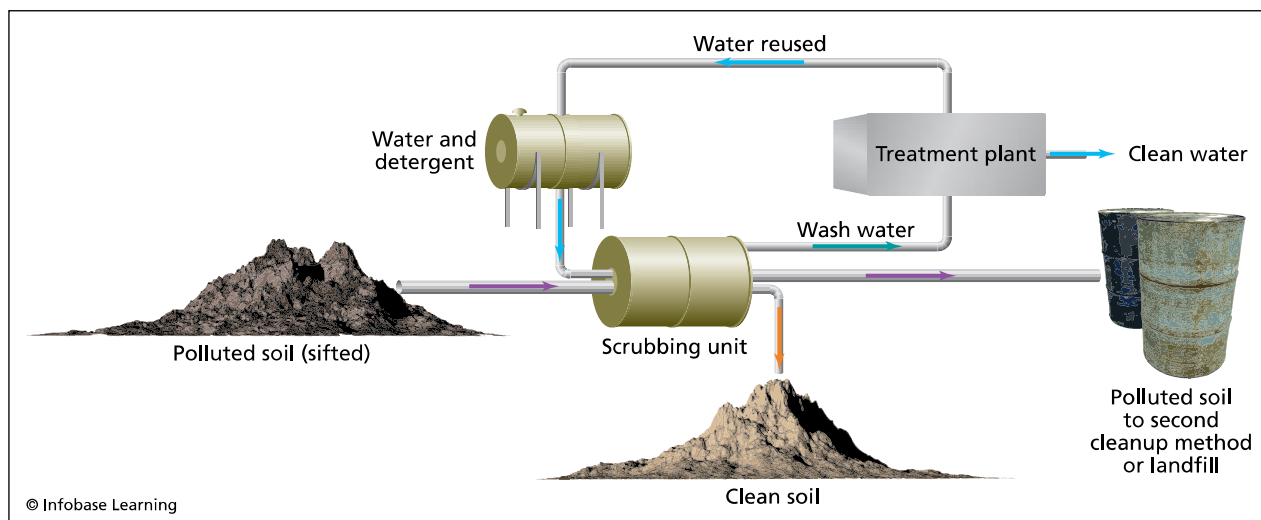
More expensive than GAC, synthetic resins can be designed to be more selective and adsorb better. They are regenerated by flushing with acids, bases, or organic solvents, but not thermal methods. For this reason, resins are better suited for explosives. They also are less sensitive to dissolved solids and tend to be more resistant to abrasion than activated carbon.

#### **ION EXCHANGE**

"Hard" water is more of a household nuisance than an environmental concern, but the equipment available to deal with it illustrates ion exchange groundwater treatment technology. As water flows through the subsurface, it dissolves certain minerals that are naturally present in the soil, especially those rich in calcium and magnesium, but also some sodium, potassium, and nitrate. Water containing high concentrations of these elements and compounds, particularly calcium and magnesium, is called hard water. Ordinary soap, which is made up mostly of fatty acids, forms an insoluble salt when mixed with calcium or magnesium. Washing with soap in hard water reduces its ability to form lather, and it produces a dingy precipitate that gives clothing a gray hue. The higher the levels of calcium and magnesium, the less lather can be made. Hard water is defined as containing more than 250 parts per million (ppm) of total calcium and magnesium ions. Hardness can also be expressed in grains of calcium per gallon, or gpg, where 17.1 ppm equals one grain of hardness.

If the calcium and magnesium dissolved in the groundwater enter a household plumbing system, they precipitate on the insides of the pipes and water heaters, forming a scale. This scale slowly builds up and eventually constricts the flow of water through the system. It also prematurely ages hot water heaters and furnaces. Water with greater than 150 ppm is hard enough to require treatment to remove the calcium or magnesium. If hardness exceeds 250–300 ppm, treatment becomes a necessity. At levels of 100–250 ppm, water treatment is done for aesthetic purposes.

Water treatment reduces staining of fixtures and surfaces, as well as making hair and skin feel softer. In an industrial steam boiler, treatment of hard water is a necessity as scale quickly interferes with water circulation and heat transfer and can catastrophically destroy the boiler. The higher the operating pressure of the boiler the more critical the



**Diagram of the basic components of a soil washing system. Contaminated soil is loaded into the scrubbing unit with water and detergent. In some cases, the system cleans the soil completely, but in others, the soil is still too contaminated to be released. The wastewater must be treated and can be either released or recirculated back into scrubbing unit.**

removal of calcium, magnesium, and other dissolved minerals from the water becomes. Large utility boilers operating at 3,000 pounds per square inch of gas (psig) or more may use distilled water to minimize scale buildup.

One of the most effective ways to treat hard water is to use a water “softener” to remove the calcium and magnesium. This is done through a reversible chemical reaction called ion exchange or ion substitution. An ion is an atom or molecule that has lost or gained an electron and thus acquired an electrical charge, either positive or negative. If dissolved in water, an ion can be easily exchanged for a similarly charged ion that is attached to an immobile solid particle.

Water is electrically neutral because the dissolved ions travel in pairs, one positively charged, called a cation, and one negatively charged, called an anion. Calcium cation ( $\text{Ca}^+$ ) present in the water is matched up with a carbonate anion ( $\text{CO}_3^-$ ) to form calcium carbonate, or the mineral calcite. Similarly, positively charged magnesium cations are connected to negatively charged carbonate anions to form magnesite ( $\text{MgCO}_3$ ). Sodium ( $\text{Na}^+$ ) is a cation that is associated with the anion chloride to form sodium chloride, or common table salt. The important characteristic of sodium is that it is “soft,” in that it does not interact with soap nor clog pipes or furnaces. This makes it ideal for use as a water softener.

To soften water by substituting sodium ions for calcium or magnesium ions, thousands of tiny, negatively charged beads are made from hardened plastic resin. Depending upon the type of material used to

make the resin, these beads can be designed with either a positive or a negative electrical charges. Next, beads are coated with a layer of sodium chloride, or salt. The negative charge on the beads will tend to attract and hold positively charged sodium ions. The negatively charged resin beads coated with positively charged sodium ions are placed in a cylindrical tank. Hard water pumped into the top of the tank flows down into the beads. The positively charged calcium and magnesium ions in the water are strongly attracted to the negatively charged, sodium coated beads. As the “hard” ions attach to the bead, they displace the “soft” sodium ions. The sodium is exchanged for the calcium and magnesium, and, at the end of this exchange or substitution process, “soft” water flows from the bottom of the tank.

Some types of water softeners use a naturally occurring claylike material called zeolite, a group of porous minerals containing sodium, aluminum, and silica. Their atomic structure is arranged so that water can easily pass through it. When this happens, the sodium ions can be exchanged for other ions dissolved in water, such as calcium and magnesium. Zeolites are somewhat less expensive to use than resin beads, but not as efficient at removing ions from water.

Eventually, the resin beads or zeolite in the tank of the water softener becomes saturated with calcium and/or magnesium and need to be renewed. The exchange or substitution process is reversible, so a strong salt solution pushed through the tank holding the resin or zeolite can flush out hard water.

The softener can be returned to service, with a fresh coating of sodium ions present on the resin beads or coating the zeolite crystals.

The ability of some materials to exchange one ion for another is a useful property in the remediation of contaminated groundwater. Environmental scientists and engineers use ion exchange or ion substitution to treat groundwater that has been contaminated by such heavy metals as copper, chromium, and lead. In this type of application, the contaminated water is run through a series of resin beds so that dissolved minerals are removed. However, to ensure effective treatment of contaminated groundwater, both the cation and the anion need to be removed or exchanged, and, since resins cannot be both positively and negatively charged simultaneously, two different types of resins are required. The most direct method is to design a system that places a positively charged cation exchange resin in one tank and a negatively charged anion exchange resin in another. Contaminated groundwater flows first through the tank holding cation resin and then the tank with anion resin. The treated water then is discharged or recirculated.

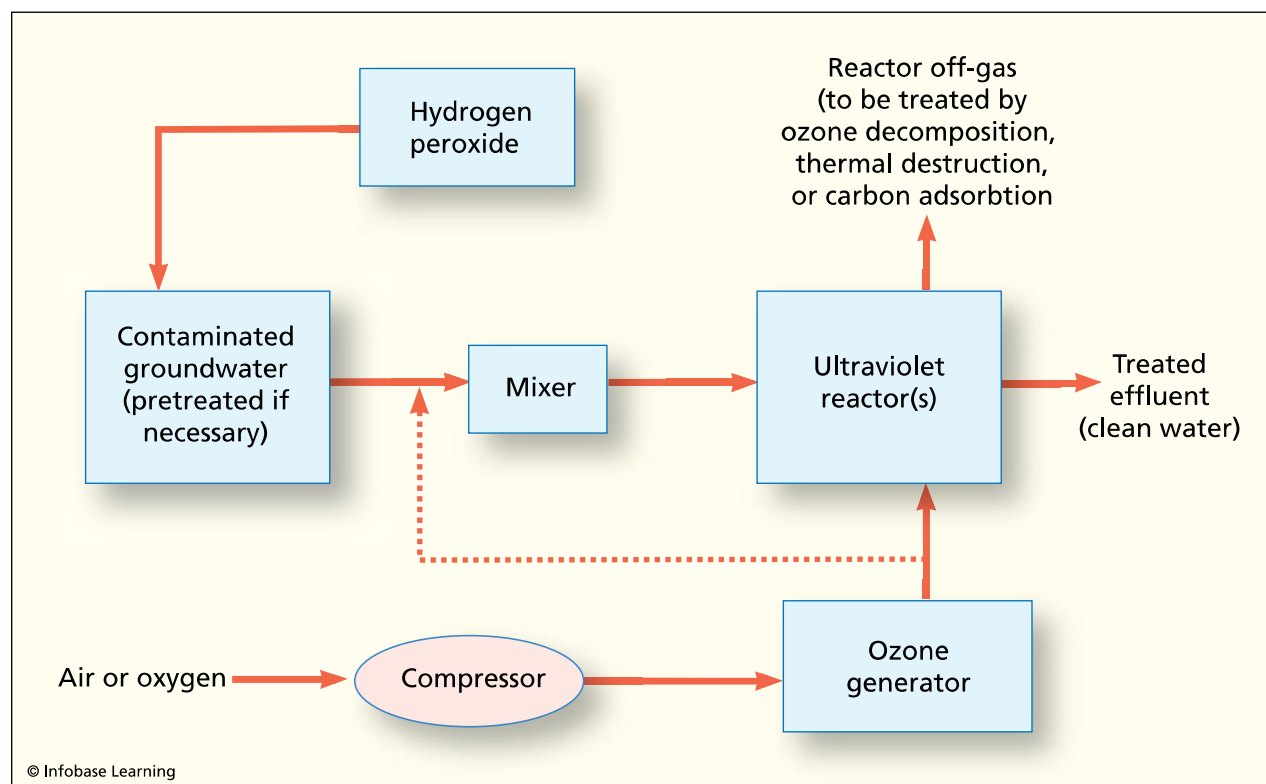
In the cation tank, specially designed high-molecular-weight polyelectrolytic resins exchange hydrogen ions ( $H^+$ ) for positively charged metallic ions

such as nickel, copper, or sodium. Treated water then moves into the anion tank, where similar resins exchange hydroxyl ions ( $OH^-$ ) for the negatively charged nonmetallic part of the mineral such as sulfates, carbonates, and chlorides. The exchange process adds the same quantity of  $H^+$  and  $OH^-$  ions to the wastewater, so the water that is discharged is pH neutral and relatively pure. Just as water softeners do, cation exchange resins need to be periodically renewed, by washing them with hydrochloric (HCl) or sulfuric ( $H_2SO_4$ ) acid.

As with carbon adsorption, ion exchange is seldom used as the primary treatment process. More commonly deployed as a polishing step, ion exchange systems can be difficult to design and expensive to operate for systems with high-volume influent flows.

### UV/OXIDATION

Ultraviolet oxidation (UV/O) is a process that eliminates contaminants from groundwater. Air stripping, GAC, precipitation, and the other technologies transfer the contaminant mass from water to another medium for easier handling and disposal. UV/O uses a two-tiered procedure to destroy a wide variety of contaminants using ultraviolet radiation in combination with ozone gas or hydrogen peroxide.



Schematic diagram showing the flow path in an ultraviolet and ozone oxidation groundwater treatment system



First, an oxidizing agent, typically ozone ( $O_3$ ) or hydrogen peroxide ( $H_2O_2$ ), is added to the wastewater. These chemicals react with contaminants in the water and break apart the chemical bonds holding them together. Whether to use ozone or hydrogen peroxide as the oxidizing agent is dependent upon what type of contaminant is present in the wastewater. Ozone works well with many types of organic molecules such as TCE, tetrachloroethylene (PCE), and vinyl chloride, as well as aromatic compounds such as toluene, benzene, xylene, and phenol. Chemicals that react well with hydrogen peroxide include nitriles, aldehydes, alcohols, amines, metals, alkylboranes, azocompounds, cyanides, phenols, sulfides, and chromium. In certain systems, both ozone and hydrogen peroxide are added as oxidizing agents.

Ozone naturally decomposes in water to form hydroxyl radicals ( $OH^\cdot$ ) and hydrogen peroxide; if an iron catalyst is added, it will do the same. These hydroxyl radicals break down contaminants at a much faster rate than just the ozone or hydrogen peroxide alone. Therefore, one way to speed up the treatment process is to increase the number and effectiveness of hydroxyl radicals that form from the addition of ozone or hydrogen peroxide to the contaminated groundwater. This is when the use of ultraviolet radiation becomes important. Once saturated with ozone, hydrogen peroxide, or both, wastewater is pumped to a tank, where it is exposed to a high-intensity, ultraviolet radiation source.

Ultraviolet light is also called ultraviolet radiation, or UVR, and is a form of electromagnetic radiation similar to visible light, radar, and radio signals. Electromagnetic radiation is transmitted in waves. UVR has a wavelength shorter than that of visible light but has a much higher frequency, or energy level. Within the electromagnetic spectrum, UVR is between the blue end of the visible range and low-energy X-rays. UVR is separated into three bands based on increasing energy levels and general biological effects:

### **UV-A**

With a wavelength of 315–400 nanometers (nm) and commonly called black light, UV-A is the least energetic UV band and less effective than UV-B in causing sunburn (erythema) and tanning. UV-A penetrates deeper in the skin because of its longer wavelength and plays a role in the premature aging of skin and increased incidence of skin cancer and eye cataracts. “Black lights” are UV-A lamps used for nondestructive testing and, insect control and in the entertainment industry.

### **UV-B**

With a wavelength of 280–315 nm, erythema UV is the most effective UV band for tanning and sunburn (erythema). It can affect the immune system. Therapeutic UVR lamps, used in physiotherapy and dermatology for the treatment of psoriasis and other skin conditions, can emit either UV-A or UV-B.

### **UV-C**

With a wavelength of 100–280 nm, germicidal UV can damage deoxyribonucleic acid (DNA) and other molecules and is often used as an antibacterial agent. The atmospheric ozone layer rapidly attenuates UV-C in air, and UV-C is not found in ground-level solar radiation. Exposure to UV-C, however, can take place close to sources such as welding arcs. Germicidal lamps, used for sterilization in hospitals, are strong emitters of UV-B and UV-C radiation.

UV-B and UV-C are powerful enough to break apart the molecular and chemical bonds present in many common groundwater contaminants. They can degrade polychlorinated biphenyls (PCBs), dioxins, polycyclic aromatic hydrocarbons (PAHs), and BTEX (benzene, toluene, ethylbenzene, xylene), but the real value of UV-B/C is that it enhances chemical oxidation, probably by increasing the number of hydroxyl radicals that form if ozone or hydrogen peroxide is added to wastewater. It is likely that the energy added to the water from the UV-B/C radiation speeds up the formation of hydroxyl radicals, and it is these radicals that attack and break apart the complex organic molecules that make up the contaminants. With a full-scale UV/ozone/peroxide system, groundwater contaminated with halogenated solvents, phenol, pentachlorophenol, pesticides, PCBs, explosives, BTEX, methyl tert-butyl ether (MTBE), and many other organic compounds can be treated effectively.

A typical UV/O system consists of an air compressor with an ozone generator and a hydrogen peroxide injection system. Passing an electrical current through a column of water generates the ozone. The water molecules are broken apart into hydrogen and oxygen atoms. The hydrogen molecules then are separated from the gas/water mixture, and the oxygen is combined to form ozone ( $O_3$ ) and oxygen ( $O_2$ ). The ozone is injected as a gas into the contaminated groundwater. Hydrogen peroxide is added as a liquid and mixed with it. The groundwater, now saturated with ozone and hydrogen peroxide, flows past a strong source of UV light. UV radiation is generated by low-pressure mercury vapor lamps that produce ultraviolet rays from an electrical discharge through low-pressure inert gases and mercury vapor within

a quartz tube. Approximately 95 percent of the UV rays from this type of lamp are at a wavelength of 254 nm (UV-C). The quartz tube prevents the water from having contact with the lamp but is transparent to UV light.

As with any remedial system, UV/O has limitations. A major factor in determining how well the UV/O system will function is the turbidity of the water. The cloudier the water, the more difficult it is to transmit the UV radiation through it. The water should be relatively free of heavy metals and insoluble oil or grease, as they tend to foul the UV lights. From an economic standpoint, these systems require large amounts of energy and can be fairly expensive to operate and maintain compared to other technologies. Finally, handling and storage of hydrogen peroxide, a very reactive chemical, require special safety precautions. Ozone is an air pollutant, and monitoring must be carried out so that ozone levels do not exceed regulatory limits.

There are several advantages to using a combined ultraviolet, ozone, and hydrogen peroxide process. UV/O is destructive, with contaminant end products of carbon dioxide, water, and inert salts. These residuals do not require further treatment. Also, a much wider variety of contaminants and concentrations can be treated with these types of systems.

## SEPARATION

Separation technologies detach or disconnect contaminants from groundwater or the suspended material that contains them. These technologies work on physical differences such as particle size, density, or vapor pressure between the contaminant and groundwater to segregate and remove them. Separation processes are some of the technologically simplest ways to address groundwater contamination.

### Coalescing Oil-Water Separators

These are passive, physical separation systems designed for the removal of oils, fuels, and hydraulic fluids from water. Oil-water separators use the difference in specific gravity between lighter oil and heavier water. Oil separates from a fluid at a rate explained by Stokes' law, which is a formula that predicts how fast an oil droplet will rise or settle through water on the basis of the density and size of the oil droplet and the distance the droplet must travel. In an oil-water separator, the water-oil mixture enters the separator and is dispersed horizontally by diffusion. Dense solids settle out in this part of the separator and light particles of oil rise to the surface.

The mixture then flows to a coalescing chamber, where it strikes a series of stacked plates. The oil combines into larger droplets and rises upward, forming a coherent layer. As the oil rises, remaining solids also strike the plates and slide down into a hopper for collection and disposal. The oil accumulates in the upper part of the separator, and when a sufficient volume has gathered, it is removed by a pump. Clean water is discharged from the bottom of the separator.

Oil-water separators typically are installed as pretreatment devices, often combined with a settling chamber. They are used to collect storm-water runoff from parking lots and gas stations before discharging the water component to the municipal sewer system for further treatment. Oil-water separators do not address chemical contaminants dissolved in groundwater, but they are effective in removing oils, greases, and other floating layers with physical differences from the water.

### Distillation

This process achieves contaminant separation by vaporization and condensation. It is based on the volatility of the material dissolved in the wastewater. In a single-stage distillation system, heat is applied to a liquid mixture in a still. This causes part of the liquid to vaporize. The vapors are collected and cooled, subsequently condensing and forming a liquid called distillate. The distillate is actually a concentrate of the higher-volatility components of the contaminants that evaporated out of the wastewater. The material remaining in the still, called the bottoms, contains components that are less volatile. In most commercial distillation operations, multiple, or repeat, staging is used to obtain better separation of organic components than is possible in a single evaporation and condensation stage.

Distillation is a common process for the purification of seawater, with salts and minerals being concentrated. Certain organic compounds and radionuclides, however, can travel with the water once it is evaporated, and GAC filters often are used in connection with distillation to make sure these unwanted contaminants are removed before the distilled water is discharged. Distillation produces very pure water and is effective in removing nitrates, chloride, and other salts that carbon filtration cannot. It also destroys bacteria and parasites that may be present in the water. Distillation, however, takes time to purify the water and uses relatively high amounts of energy. Maintenance requirements for these types of systems also are extensive.

### Freeze Crystallization

This process removes contaminants from solution as frozen crystals. Groundwater slowly is frozen and ice crystals form on its surface. The contaminants are concentrated in the unfrozen remaining solution, called mother liquor. The ice crystals then are collected, washed, and melted to form relatively pure water. Mother liquor and related precipitated solids are now more easily treated because of their higher concentrations.

Freeze crystallization is used at many winter resorts to treat the higher volumes of sanitary wastewater that are generated during ski or winter holiday seasons. In Ottawa, Canada, freeze crystallization is used during winter months to help manage that city's sanitary wastewater. In freezing weather, and after solids separation, wastewater is pumped at high pressure to atomizing nozzles, where compressed air sprays fine droplets into the atmosphere. Spraying cause gases such as carbon dioxide to be stripped away, raising pH values. Higher pH encourages a variety of beneficial chemical reactions within the meltwater. As the droplets freeze, water is transformed into hexagonal crystalline structures that reject incorporation of impurities. As a result, contaminants are physically separated from the water but remain trapped within the center of the frozen droplets.

The ice particles accumulate in the snowpack throughout the winter, degrading as they age. Nutrients, such as phosphorus, precipitate in insoluble form and do not redissolve into the melting snow. Other soluble salts also precipitate and organics collect on the precipitating salts. As ice crystals in the snowpack age, they fuse together, forming larger crystals called corn or sugar snow. This allows some of the entrapped contaminants to escape as gases, and others, as precipitated solids, move to the bottom of the snowpack. Depending on soil characteristics, meltwater from the snowpack either infiltrates or can be collected for later treatment or discharge. The soil beneath the snowpack generally remains frozen during winter, so infiltration of meltwater begins early in the spring. The nutrient residues left after meltwater dissipates provide a weak fertilizer for on-site vegetation, such as grasses.

### Filtration

Filtration works by forcing groundwater through a porous medium that mechanically separates or traps the particles suspended in it. Particles whose sizes are smaller than the openings of the medium or semipermeable membrane are allowed to pass flow through the membrane. Depending upon the size of the trapped particles, filtration can be classified

as microfiltration (pore size greater than 50 nm) or ultrafiltration (pore size 2–50 nm). A number of commercial filtration systems are available, most based on the use of specialty fabrics or composites. Limiting the widespread use of filtration as a remedial solution are relatively high maintenance costs associated with filter change out and the need for subsequent treatment and disposal of collected solids.

### Membrane Pervaporation

Membrane pervaporation is a process that uses permeable membranes preferentially to adsorb volatile organic compounds (VOCs) from contaminated water. A heat exchanger first raises the temperature of contaminated water. From there, it is pumped through a pervaporation unit. This contains semipermeable membranes made up of a nonporous material shaped into capillary fibers that attracts organic and oily substances and repels water. Nitrile, butadiene rubber, and styrene butadiene rubber are types of materials used. A vacuum is applied to one side of the unit and VOCs diffuse through the membrane. Treated water flows out of the pervaporation unit and the VOCs in vapor form are captured by a condenser and collected for separate disposal. The condensed VOCs are only a fraction of the initial contaminated water volume and, therefore, disposal costs are greatly reduced.

Over time, as material flows through the membrane, a swelling effect makes it more permeable and less selective. Eventually, the membrane is exhausted and must be replaced or renewed. Continuous pervaporation consumes relatively low amounts of energy and operates most efficiently at low contaminant concentrations. It is also better suited for high wastewater flow rates.

### Reverse Osmosis

There are two mechanisms by which molecules move through a membrane, active and passive transport. Active transport requires energy to transport molecules through the membrane and is commonly seen in living organisms as water moving in or out of a cell. Passive transport occurs spontaneously and is governed by the principle of diffusion.

Diffusion is the net movement of molecules from an area of high concentration to an area of low concentration. Diffusion is dependent on temperature and continues until the molecules are randomly distributed throughout the system. Osmosis is a type of diffusion. If two water or other solvent volumes are separated by a semipermeable membrane such as a cell wall or piece of porous rubber, water will flow from the side of low solute concentration to the side of high solute concentration. If a volume

of salt water is separated from a volume of freshwater by a semipermeable membrane, for example, the freshwater will move, by diffusion, through the membrane toward the salt water. This diffusion, or osmosis, continues until the concentration of salt in the water is the same on both sides of the membrane. The final pressure difference between the two sides of the membrane is equal to the osmotic pressure of the solution.

To reverse the flow of water or solvent, pressure greater than the osmotic pressure is applied. If this occurs, the solvent (water) separates from the solute (the groundwater contaminant) and moves through the semipermeable membrane. This is reverse osmosis, sometimes called hyperfiltration, because the semipermeable membrane essentially acts as a filter to retain the ions and particles while allowing water to flow through. Purified water passing through the membrane is called permeate, whereas liquid containing the retained metals is the concentrate. Metal or salt products can be removed from concentrate by evaporation or precipitation. The three most commonly used membrane materials are cellulose acetate (processed wood pulp); aromatic polyamide, a film-forming polymer such as Kevlar; and membranes made of thin-film, solute-rejecting composites.

Membranes can degrade or foul, so pretreatment of wastewater is often necessary to remove suspended solids or solids formed by precipitation of iron or manganese. Very high or low pH can also result in membrane degradation. The reverse osmosis process is not ion selective, so it captures all ions, not just the unwanted ones. The process also can generate significant amounts of residues that require further treatment or disposal. Reverse osmosis, however, removes most contaminants and is a well-known remediation technique for groundwater. It is used for the removal of dissolved solids, especially organics and nitrates, from water.

### SPRINKLER IRRIGATION

One of the simplest remedial technologies available for treating groundwater contaminated with VOCs is to spray it in the air through a sprinkler irrigation system. The sudden increase in surface area caused by spraying encourages the VOCs to move from the dissolved aqueous phase to the vapor phase. The VOCs vaporize and are released directly into the atmosphere.

This type of remedial approach is severely limited in its application. It is not appropriate for groundwater containing nonvolatile compounds such as metals or radionuclides. Regulatory approval for it is

difficult to obtain, unless the VOC concentrations are very low, because of the uncontrolled release of contaminants to the atmosphere. Significant land area is needed to install and operate the system, and runoff of accumulated spray may result in erosion, nuisance ponding, or surface water quality issues. The effectiveness of the system is dependent upon higher temperatures, and the system loses efficiency during winter months. Finally, suspended solids or solids formed by precipitation of iron or manganese can plug spray nozzles, requiring frequent maintenance or even pretreatment.

### CONSTRUCTED WETLANDS

Since the early 1700s, wetlands such as swamps, bogs, marshes, and sloughs were regarded by most as wasted and unproductive property. Long recognized as a breeding ground for “night vapors,” “bad air,” insects, and other pests, wetlands provoked public and scientific disdain that peaked in the late 1800s, when a young doctor from Johns Hopkins Medical School let a mosquito in a yellow fever ward bite his hand. Twelve days later, this doctor died, but he proved that mosquitoes, not people, transmitted yellow fever. With this finding, there was a rush to fill wetlands, legitimized by public health concerns and fueled by money realized as part of the redevelopment process. Large parts of New York City, New Orleans, San Francisco, and Philadelphia are built on “recovered” wetlands. By the mid-1950s, more than half of the wetlands in the United States had been drained, filled, farmed, or paved.

By the 1960s and 1970s, attitudes began to change as the environmental movement took hold and biologists and engineers began to realize that wetlands play a crucial role in ecosystem habitat, flood management, and pollution control. A turning point in the understanding and appreciation of wetlands occurred in 1994, when new federal legislation greatly restricted filling or destruction of wetlands and required that natural wetlands not already drained be preserved for wildlife and as part of an existing hydrologic system.

The use of wetlands as a groundwater treatment mechanism is a fairly new and still somewhat innovative concept. The technology relies on the organic materials, microbial fauna, and algae naturally present in wetland systems to attack and breakdown contamination. Water with organic contaminants such as VOCs or S(semi)VOCs, low pH from acid mine drainage, or containing metals flows through the aerobic and anaerobic zones of the wetland. Ion exchange, adsorption, absorption, and precipitation through geochemical and



microbial oxidation and reduction remove organic contaminants and heavy metals. Sorption of metals also takes place as water has contact with humic and other organic substances in wetland sediment. Oxidation and reduction occur in the aerobic and anaerobic zones, respectively, and transform or degrade organics and precipitate metals as hydroxides and sulfides. Precipitated and adsorbed metals settle in quiescent ponds or are filtered out as the water percolates through the sediment. Wetlands can remove fecal coliform, total petroleum hydrocarbons, and such metals as lead, chromium, and zinc. Constructed wetlands are used in municipal sanitary wastewater treatment for managing organic matter, excess nitrogen and phosphorus, and suspended solids.

Constructed wetlands are of two basic types, free water surface and vegetated submerged bed. Both types can include liners to reduce the likelihood of contaminants' reentering the groundwater. Free water surface (FWS) wetlands are those that look most natural. They include open-water areas with changing water depths and emergent or visible vegetation. Distinguishing FWS wetlands from naturally occurring wetlands are inlet devices designed to control wastewater distribution into the system, soil or earthen dikes that define the treatment cells, and carefully organized combinations of open water areas and vegetation that optimize treatment. An outlet structure completes the system and is used to manage water levels within the wetland as well as discharge.

Vegetated submerged bed (VSB) wetlands contain most of the same features as FWS systems including inlet and outlet structures and treatment cells defined by earthen dikes or berms, but they are much simpler in design. VSB wetlands are essentially layers of gravel that have been planted with various types of wetland vegetation. In this system, the water level is maintained below the top of the gravel layer and areas of free-standing water are not visible. Water treatment takes place within the gravel beds.

Several factors limit the applicability and effectiveness of constructed wetlands as a remedial technology. Depending upon the types of contamination and their concentrations, a fairly large (tens of acres) land area may be needed to develop an effective treatment approach. And the long-term effectiveness of constructed wetland treatment is not well known. Contaminant removal rates may decrease over time and require the installation of a new technology or an expansion of the wetland. Local climate or even seasonal weather patterns also play a pivotal role in the success of this technology. Cold air temperatures can slow biological processes and result in inconsis-

tent contaminant degradation rates. Excess precipitation can flood a system, and below-normal rainfall amounts (drought) can damage or destroy needed vegetation.

See also BIOREMEDIATION; CADMIUM; CHLORINATED SOLVENTS; DIOXIN; INORGANIC POLLUTANTS; IN SITU GROUNDWATER REMEDIATION; LEAD; MTBE; ORGANIC POLLUTANTS; OZONE; PAH; PCBs; RADIATION; TCE; VOLATILE ORGANIC COMPOUNDS; WATER POLLUTION; WELLS; WETLANDS; ZINC.

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## **Exxon Valdez oil spill Prince William Sound, Alaska March 24, 1989 Water Pollution**

ExxonMobil is one of the world's largest companies and has been for several years. It also is the biggest oil producing and refining business on the planet, with the most proven reserves. John D. Rockefeller founded the Standard Oil Trust, or simply Standard Oil Company, in the early 1880s, to process and distribute industrial greases, lubricants, and kerosene. The company moved into petroleum and grew into a giant based on what its critics feel were questionable business tactics. In 1911, after long litigation, the U.S. Supreme Court ordered that Standard Oil be broken up into separate, independently operated companies. Eventually 34 were established and two would become the predecessor companies of Exxon and Mobil, Standard Oil of New Jersey (later Esso) and Standard Oil of New York, or Socony.

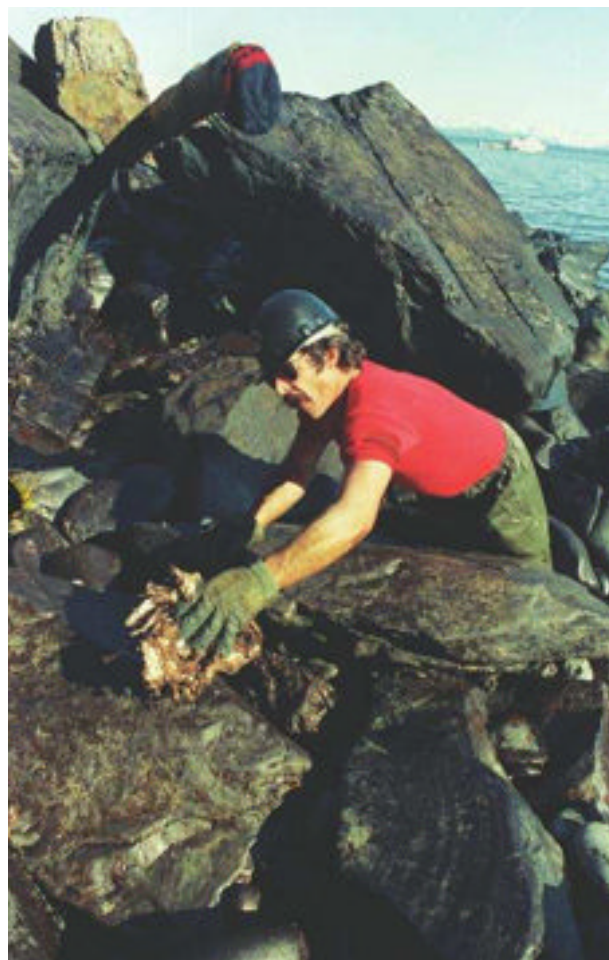
Over the next 60 years, both companies developed as major worldwide suppliers and refiners of petroleum, industrial chemicals, and related products. Exxon was the largest American oil company for most of this time. To prosper in the business and regulatory climate of the 1980s and 1990s, their emphasis shifted to the import and marketing of oil rather than exploration and discovery. In 1998, Exxon and Mobil agreed to merge and become ExxonMobil Corporation.

### BACKGROUND

It came as no surprise that, in the early 1980s, Exxon commissioned the construction of the largest ship ever built on the West Coast of the United States to date. At 987 feet (300 m) long and 166 feet (50 m) wide, the *Exxon Valdez* was built to carry 1.5 million barrels (238.5 million L) of oil from terminals in Valdez, Alaska, to refineries 800 miles (1,288 km) away in the continental United States. With a crew of 21, and powered by an eight-cylinder reversible, slow-stroke marine diesel engine, the *Exxon Valdez* could cruise at 21 knots (about 19 miles per hour, or 30.6 km/h) fully loaded. The *Exxon Valdez* was built to meet all international and U.S. safety standards. It had a unwelded hull, which is considered much stronger than a riveted hull, and the 10 cargo tanks, four ballast tanks, and two “slop” tanks were designed to provide maximal stability and cargo management flexibility in the event of damage. The *Exxon Valdez* also had incorporated one of the major safety improvements required of all new tankers being constructed at the time, a double bottom.

As the name implies, a double-bottom ship is one that has two watertight layers installed along the part of the hull in contact with water. The outermost steel skin is separated from the inner one by several feet, and, in the event of a breach of the outer hull, the inner hull prevents seawater from entering the vessel, or the vessel’s cargo from spilling into the sea. The annular space (the area between the hulls) is sometimes used to store ballast water and operating fuel. Double bottoms have been required on passenger ships for more than 30 years because of their higher safety rating.

The *Exxon Valdez*’s keel was laid on July 29, 1985, and she was delivered, after three months of sea trials, on December 6, 1986. The ship performed satisfactorily for more than three years, regularly making the journey up the West Coast of North America to the port of Valdez in Alaska. There it would transport oil from the Alaskan oil fields to refineries along the West Coast. Economically significant quantities of oil had been suspected to be pres-



Oil-absorbent rags used to wipe crude oil, spilled from the *Exxon Valdez*, off rocks on the beach of Naked Island, Prince William Sound, Alaska, April 7, 1989

ent in Alaska’s North Slope, but it was not until the late 1960s that oil prices had risen to high enough levels for Atlantic Richfield Company (ARCO) and Humble Oil (Exxon) to attempt the very expensive exploration studies needed in this harsh climate to confirm that a major oil field existed at Prudhoe Bay, near the Arctic Ocean. Both companies, joined by several others, formed a consortium that would become the Alyeska Pipeline Service Company. They proposed an 800-mile- (1,288-km-) long pipeline to convey the oil from Prudhoe Bay, near the Arctic Ocean, to the port of Valdez (population 4,000), where it could be loaded onto tanker ships for delivery to refineries in the United States. Valdez was chosen as the terminus of the Trans Alaska Pipeline System (TAPS) because it was an “ice-free” harbor. That is, the water did not routinely freeze during the long and very cold Alaskan winter, and, therefore, oil loading and shipping operations could take place year round.

When proposed in 1970, TAPS was an \$8-billion effort and one of the largest privately financed construction projects ever attempted. ExxonMobil has a 20 percent interest in the pipeline, along with such other oil companies as BP, ConocoPhillips, and Unocal. Environmental concerns slowed federal and state approval of the project, but they were eventually granted primarily because of the concern induced by the OPEC (Organization of Petroleum Exporting Countries) oil embargo of 1973. Pipeline construction began in March 1975 and was completed in May 1977. Oil from the Prudhoe Bay fields began to flow into terminals in Valdez on July 28, 1977, and the first fully loaded oil tanker, the *Arco Juneau*, sailed out of Valdez harbor toward California on August 1, 1977. Today, 70 tanker vessels sail into and out of Valdez every day, taking their important and very valuable cargo to the mainland United States.

### THE ACCIDENT AND OIL SPILL

The *Exxon Valdez* arrived at the port of Valdez on March 23, 1989, captained by Joseph Hazelwood, a very qualified and experienced skipper who had been sailing for Exxon for almost 20 years. Only three years old, the *Exxon Valdez* was the newest and most modern ship in the Exxon fleet, and it was quickly loaded almost to capacity with 1.3 million barrels (206.7 million L) of crude oil. By 9:00 p.m., it was ready to depart, and Hazelwood ordered the ship under way. Sailing southward, the *Exxon Valdez*, under the guidance of the harbor pilot, made its way safely through Valdez Narrow, the very tight (only 1,700-yard- [1.6-km-] wide) entrance to the harbor, and out into the somewhat more open waters of Prince William Sound.

Prince William Sound is an extension of the Gulf of Alaska. Lying east of the Kenai Peninsula, it is an open expanse of water some 100 miles (160.9 km) wide bordered on the east, north, and west by the Chugach Mountains. Glaciers have taken millions of years to carve out the approximately 3,000 miles (4,828 km) of shoreline surrounding the sound, and it is dotted with small islands, submerged ledges or reefs, and drowned river valleys (fjords) that form natural breakwaters and shelters from the winds and ice that originate from the Columbia Glacier along its northwestern side. These drowned valleys, reefs, and islands also form an important habitat for numerous types of seabirds, marine life, and commercial fisheries. Long recognized as a place of

pristine beauty and special ecological significance, the majority of the land surrounding Prince William Sound has been designated as national forest since 1907. In fact, Chugach National Forest is the second largest national forest in the United States, and, in 1974, Congress passed the Alaska National Interest Lands Conservation Act to help preserve the wilderness quality of this special area.

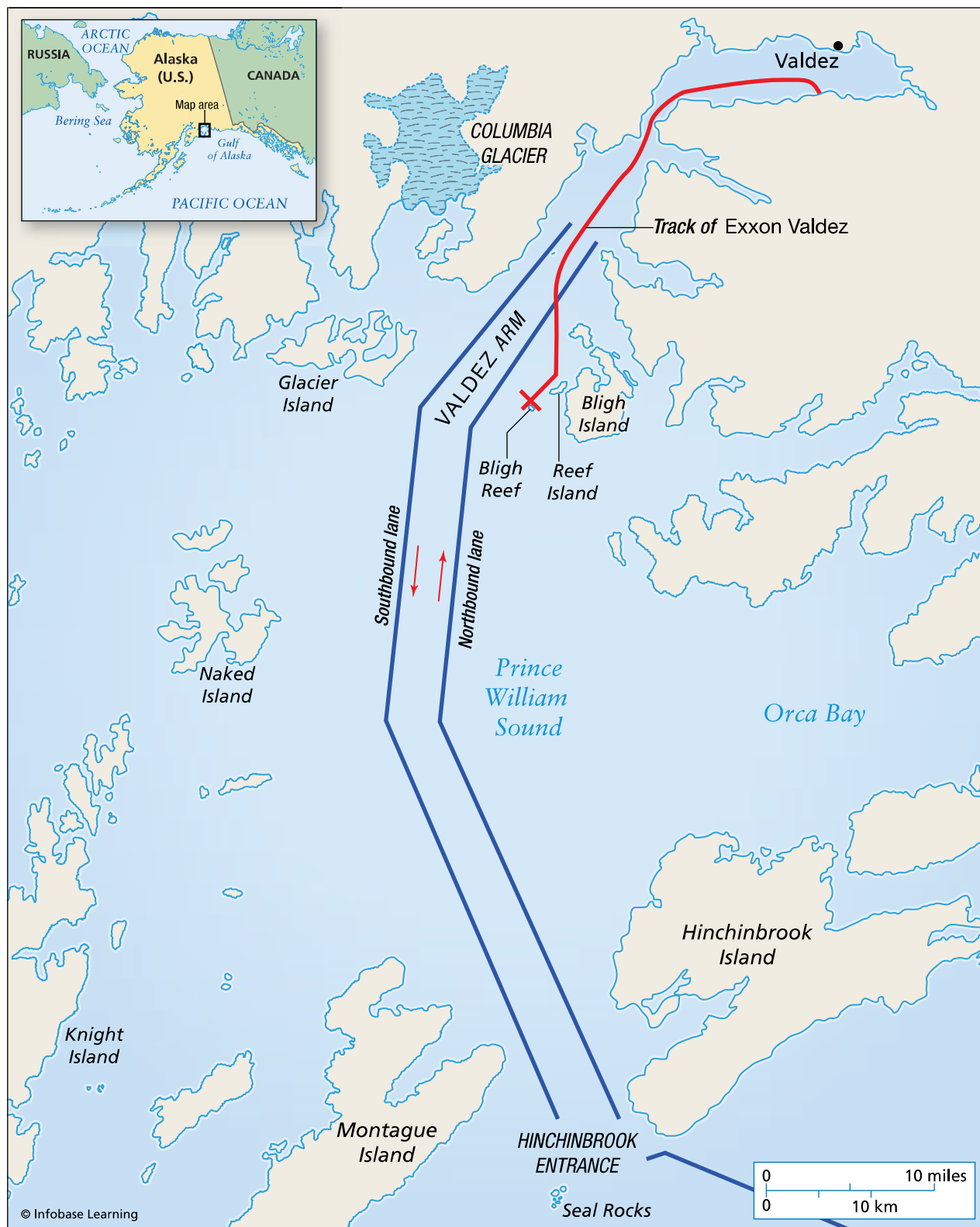
After clearing the Valdez Narrow, the harbor pilot disembarked, and the *Exxon Valdez* entered the outbound, southward shipping lanes. These well-charted and clearly marked lanes, which hug the western side of Prince William Sound, were created by the U.S. Coast Guard to control traffic into and out of the port. The weather was clear (four mile [6.44 km] visibility), although some low clouds and fog were present with only a slight breeze. Captain Hazelwood ordered the ship to accelerate to “sea speed,” or about 20 knots (23 miles per hour or 37 km/h). At around 11:30 p.m., Captain Hazelwood asked permission from port traffic control to divert eastward into the northbound, or incoming, sea-lanes to avoid floating ice that had been reported as present in the southbound lanes. It was a prudent request, although, since then, some experts have suggested that a better plan would have been to reduce speed and maneuver his way through the ice floes. Nonetheless, port traffic control gave Captain Hazelwood permission to change course as there would be no incoming ships in those lanes for several more hours, and the *Exxon Valdez* steered eastward. Hazelwood’s plan was to sail through a mile- (1.6 km-) wide gap in the ice floes, between the eastern edge and Bligh Reef, a series of submerged rocks along the far eastern edge of the northbound, or incoming, shipping lanes. Once through the ice, the *Exxon Valdez* would turn quickly westward and reenter the southbound shipping lanes. Because this maneuver required expert timing and impeccable navigation for a ship longer than three football fields, it is difficult to understand why Captain Hazelwood left the bridge and turned over control to a relatively new third mate, one who did not have the necessary rating to pilot the vessel.

The junior officer had been instructed to turn starboard, or right, back toward the southbound shipping lanes when the navigational beacon on a small patch of rock called Busby Island was spotted. With his attention divided between trying to spot the leading edge of the ice floe on radar and worrying about when to start the turn, the relatively inexperienced third mate missed the Busby Island light

(opposite page) Map of Prince William Sound, Alaska, showing the shipping lanes in and out of Valdez, Alaska, and the route that the *Exxon Valdez* tanker followed when it ran aground and released oil

and, when a crewwoman standing watch near the bow reported that the flashing buoys of Bligh Reef were coming up fast, the third mate knew he was in serious trouble. He ordered an immediate “hard to

starboard,” but it was too late—at almost full speed the *Exxon Valdez* ploughed 600 feet (182.9 m) up into the rocks of Bligh Reef shortly after midnight on Friday, March 24, 1989.





The collision and subsequent failed maneuvers by Captain Hazelwood to rock the *Exxon Valdez* back off the reef tore holes in the four main cargo tanks, along most of their entire lengths. Along the starboard side of the ship, the double-hulled bottom was ripped open and oil began to pour into the sea. Within 30 minutes of the grounding, more than 110,000 barrels of oil (more than 4.6 million gallons, or 17.4 million L) entered the protected waters of Prince William Sound. Within eight hours, 215,000 barrels (more than 9 million gallons, or 34.1 million L) were discharged. Eventually, almost 260,000 barrels (approximately 11 million gallons, or 41.6 million L), or 20 percent of the *Exxon Valdez*'s cargo of oil, found its way into the sea.

For 10 years, loading and transport of oil at the port of Valdez had occurred without serious incident. Although several localized spills had taken place, one of the most notable that of the BP tanker *Thompson Pass*, which had lost 1,700 barrels (71,400 gallons, or 270,300 L) during a loading operation, most spills were small and able to be readily contained. The *Exxon Valdez* was the first true test of the oil spill response plans that had been developed for the port, and it did not go well. The emergency response barge was in dry dock, damaged in a storm several months earlier and still awaiting repairs. Booms and skimming equipment could not be loaded because they were in a warehouse, and only one equipment operator was available to run the forklift and crane needed to load them onto the damaged response barge, which put to sea despite a crack in its bow. It would take 14 hours for the barge to reach the wrecked ship, and by then the slick covered almost 20 square miles (51.8 km<sup>2</sup>). The *Exxon Valdez* had grounded so close to shore that Alaskan environmental officials were hesitant to allow the use of dispersants for fear that they would result in long-term damage to the local ecology. Lightering, or transfer of the oil remaining on board, was delayed over concerns that the *Exxon Valdez* would capsize and sink if the cargo were removed too quickly and because the portable pumps needed to transfer the oil could not be located. Initially, the calm weather helped keep the slick near the grounded vessel. That changed quickly, however, when strong winds and rough seas began to push the oil toward the shoreline. More than 1,200 miles (1,931.2 km) of rocky beaches were coated with oil by the *Exxon Valdez*'s cargo.

### THE CLEANUP

Throughout summer 1989, Exxon mobilized more than 10,000 workers to assist in the cleanup. Total spill response costs were estimated by Exxon to be

approximately \$2 billion, with the majority of the work completed by September 1989. Although several methods were attempted to control the shoreline spread of oil, including limited use of trial burns and dispersants, most of the removal activities were accomplished through manual recovery. Workers with mops, buckets, and steam cleaners attacked sections of beach and tried to collect the oil physically or dissolve it so that it could be washed back into the sea and captured by skimmer ships waiting just offshore. This technique was not very quick or efficient, and many experts claimed that the associated pressure washing used to push the oil off the beach damaged the sensitive local ecology.

Later studies found that three months after the release of the 11 million gallons (41.6 million L), 6 percent (660,000 gallons, or 2.5 million L) had been recovered by skimming and other sea recovery operations; 18 percent (1.9 million gallons, or 7.2 million L) had either evaporated or been broken down by photodegradation from sunlight; 28 percent (3.1 million gallons, or 11.7 million L) had emulsified and been dispersed into the water column; and almost half (48 percent, or 5.3 million gallons, or 20.1 million L) had washed up on the beaches and shorelines of Prince William Sound. Approximately 250,000 birds were killed, along with almost 3,000 sea otters and 200 harbor seals. Fishing for herring and salmon was banned for that year, and many claim those stocks have not recovered to predisaster levels to this day. Even though few effects of the spill remain visible at the surface, along many shorelines a layer of oil is present only a few inches below the rocky beach cover.

### THE AFTERMATH

Investigations by the Coast Guard, the Alyeska Corporation, Exxon, the EPA, and Alaskan environmental officials distilled the causes of the accident down to several reasons. The primary one was that the third mate failed to execute the ordered westward course correction maneuver in a timely manner. This failure was directly related to fatigue—he was functioning on only a few hours of sleep after supervising oil loading operations—as well as a lack of command support on the bridge. Captain Hazelwood, who had been drinking prior to departure, failed to ensure that the ship was being navigated correctly before leaving the bridge. Contributing factors included Exxon's unwillingness to relieve Captain Hazelwood of command, despite previous knowledge of a substance abuse problem, and the fact that both the Coast Guard and port of Valdez traffic control radars were antiquated and inadequately staffed.

The political and regulatory implications of the spill were far-reaching. The Alyeska Pipeline Company significantly revised its oil spill response procedures and greatly expanded its reaction capability. Sufficient equipment and vessels now are stockpiled to manage spills in the 300,000-barrel (47.7 million L) range quickly and effectively. The U.S. Coast Guard has improved its radar system and strictly forbids ships to change shipping lanes, except in the event of an emergency. Tanker captains also are given a sobriety test one hour before sailing, and a 10-knot (11.5 miles per hour or 18.5 km/h) speed limit is strictly enforced. The U.S. Congress was so incensed by the spill that it quickly passed the Oil Pollution Act (OPA) of 1990. OPA included a clause forbidding any ship that had released more than 1 million gallons (3.8 million L) of oil in a spill ever to enter U.S. waters again. The *Exxon Valdez* was the only ship that met this criterion. After \$30 million in repairs at the same San Diego shipyard where it was built, Exxon renamed the vessel the *Sea River Mediterranean*, and it now regularly transports oil from the Persian Gulf to Europe. It has an impeccable safety record. Exxon, as have many of the major oil companies, also has removed its name from the other ships in its fleet.

The OPA also requires the phasing in of double hulls, not just double-bottomed vessels, docking at U.S. ports. Although a double hull would not have prevented the *Exxon Valdez* spill, the amount of oil released would have been significantly reduced. OPA raised liability limits for oil transporters and established a fund (paid for by a \$0.05 tax per barrel of oil) to help pay for cleanups when the shipowner cannot.

Exxon pled guilty to violations of several environmental laws, including the Clean Water Act, the Refuse Act, and the Migratory Bird Treaty Act. The corporation settled its civil and criminal liability claims with the federal government and the state of Alaska for \$1.025 billion. A 2006 court judgment also ordered Exxon to pay fishermen and residents of

the Prince William Sound area \$2.5 billion in compensatory and punitive damages. Exxon appealed this decision to the U.S. Supreme Court, which ruled in June 2008 that the award was excessive and reduced the amount to slightly more than \$500 million. The bulk of the award would be distributed to the Alaskan fishing industry, with about 20 percent going to lawyers. The 32,677 private party plaintiffs would divide the remaining funds. Joseph Hazelwood had his master's license suspended but not revoked and was found guilty of negligent discharge of oil. He was fined \$50,000 and sentenced to 1,000 hours of community service, of which he served more than five years by picking up trash along Alaskan highways and working in a soup kitchen. The former captain of what was one of the largest oceangoing vessels ever built leads a quiet life, far from the public eye, and reportedly makes his living today working as a paralegal and maritime consultant and occasionally serving as a deckhand on commercial fishing boats.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS.

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# F

## **Fairchild Semiconductor San Jose, California 1981 Water Pollution**

Between 1977 and 1983, the 20-acre (8.1-ha) Fairchild Semiconductor (Fairchild) facility in San Jose, California, was one of the leading manufacturers of semiconductors in the United States, making the early 286 and 386 computer chips that powered the beginnings of the information technology revolution. Some of the country's best and brightest minds worked together at the San Jose plant to design and create groundbreaking computer technologies and systems. It was for this reason that it was surprising when they failed to notice that the underground storage tank (UST) used to store waste solvents, primarily 1,1,1-trichloroethane (TCA) and 1,1-dichloroethene (DCE), never seemed to fill up. In late 1981, this tank was found to be leaking, but by then an estimated 60,000 gallons (227,125 L) of spent solvents had been released to the soil and groundwater. As a result of this release, groundwater in a public drinking supply well 1,800 feet (549 m) downgradient of the site became contaminated with TCA at concentrations of up to 7,700 parts per billion (ppb). The drinking water standard for TCA at the time was 200 ppb. This well was taken out of service and eventually sealed (filled with concrete), but other wells in the area remained active. Additional contaminants detected in soil and groundwater as a result of the Fairchild release included perchloroethene (PCE), freon 113, and xylenes.

### **REMEDICATION OF THE SITE**

Once the contamination was discovered, Fairchild entered into a cooperative agreement with the U.S. Environmental Protection Agency (EPA) and the

state of California. The defective tank and approximately 3,400 cubic yards (2,600 m<sup>3</sup>) of heavily contaminated (solvent-saturated) soil were removed and disposed of off-site. After conducting a site investigation to identify the nature and extent of the contamination, Fairchild's Feasibility Study concluded that soil vapor extraction (SVE) was the most appropriate way to clean up the remaining polluted soil.

If soil is contaminated with volatile organic compounds (VOCs), typically by the release of solvents or petroleum hydrocarbons stored in underground tanks, the in situ remedial technology that usually is considered first is soil vapor extraction, or SVE. Pioneered in the early 1980s as an alternative to excavation and off-site disposal of polluted soil, SVE (also known as soil venting or vacuum extraction) reduces the concentrations of volatile constituents adsorbed primarily to the clay and organic particles in the soil. This is done by applying a vacuum to a series of extraction wells that have been drilled into the contaminant mass just above the water table in the vadose zone. A negative pressure is created, forcing air to pass through the contaminated soil and evaporating the volatile constituents. The vapors are captured in the extraction wells and treated at the surface, usually passing through a granulated activated carbon (GAC) filter or afterburner prior to venting to the atmosphere. In some cases, depending upon the geometry of the contamination, extraction wells are installed horizontally across the impacted area.

SVE is most successful when used to remediate soil contaminated with VOCs that evaporate easily, which are those that have a relatively high vapor pressure, greater than 0.02 inch Hg (0.5 mmHg). Vapor pressure is the force exerted by the gas given off by a substance that is in equilibrium with respect

to the liquid or solid phase of that substance at a given temperature or pressure. In other words, vapor pressure measures the tendency of a compound to transfer or move from solid or liquid phase to gaseous phase. An example of a compound with a high vapor pressure is acetone, which was the main ingredient in nail polish remover. Acetone, under standard temperature and pressure conditions, or STP, has a high vapor pressure (229.92 mmHg). It moves quickly from liquid state to gaseous state.

Organic compounds such as benzene (vapor pressure of 100.84 mmHg) and toluene (vapor pressure of 28.47 mmHg), the principal constituents of many industrial solvents as well as gasoline, have high vapor pressures. Released to soil, they quickly evaporate, especially with a little encouragement. This encouragement is provided when an SVE system lowers the atmospheric pressure in the soil and creates a disequilibrium between the gaseous phase and the liquid phase of the benzene or toluene, and, to overcome that disequilibrium, the benzene or toluene changes from a liquid to a gas.

If the ground is water-saturated, VOC dissolves into the water, and Henry's law constant (usually denoted as  $K_H$ ) is used to measure how easily the material (VOCs) evaporates from an aqueous solution. Almost all chemicals dissolve to one extent or another in liquids to form solutions. The solubility

of a compound in a liquid depends on the type of compound it is, the temperature, and the pressure of the gas over the liquid. For example, clean (noncontaminated), well-mixed surface water usually contains about 10 mg/L of dissolved oxygen. How easily the oxygen will be released from the water is dependent on the temperature and pressure of the atmosphere just above the water's surface. The higher the temperature and the lower the pressure, the more easily the oxygen will move out of the water and into the atmosphere. Henry's law constant measures this tendency.

Similarly, organic compounds such as benzene or toluene dissolve to a certain extent in water at standard temperature and pressure. At lower atmospheric pressure, solubility decreases and the compound(s) evaporates into the atmosphere, on the basis of its  $K_H$ . Henry's law constants provide an indication or measure of how readily a substance moves from a liquid solution into a gaseous phase. Benzene has a  $K_H$  of 0.005, whereas toluene's  $K_H$  is 0.007. When the contaminant is dissolved in the groundwater, SVE works best on compounds with  $K_H$  greater than 0.001. The less soluble a compound is in water, the more difficult it is to volatilize.

In designing an SVE system, one of the most important considerations is the radius of influence, or ROI. This is the maximal distance over which



Fairchild Semiconductor wafer production facility in South Portland, Maine, 1999 (AP Images)



an extraction well can generate a sufficient vacuum and vapor flow to induce volatilization and removal of contaminants present in the soil. The shape and extent of ROIs depend on the type of soil, the depth and arrangement of the extraction wells, and the power (rating or size) of the vacuum pumps being used. Usually, extraction wells are placed so that ROIs overlap, to ensure that all contaminated areas are covered by the system.

One technique used by engineers to increase the size and effectiveness of ROIs is to install a surface seal over the area to be treated. These seals, usually plastic membranes but sometimes asphalt or concrete, help reduce surface water infiltration that slows airflow. Surface seals also prevent vertical short-circuiting of airflow. This occurs if air is drawn from other areas of the site and not through the contaminant mass. The lower pressure gradients that occur when a surface seal is used, however, often decrease airflow velocities and typically require the use of bigger, more expensive vacuum pumps.

The SVE system that Fairchild installed at the San Jose site consisted of 39 extraction wells that were designed to have ROIs to treat 42,000 cubic yards (32,111 m<sup>3</sup>) of soil made up primarily of alluvial sand, silt, and clay. Air from the extraction wells was pumped through a dehumidifier and then a carbon filter that adsorbed the solvent-rich vapors. Samples that were taken prior to SVE system startup showed soil with maximal TCA and DCE concentrations of 3,530 mg/kg and 17 mg/kg, respectively. The California Regional Water Quality Control Board (CRWQCB) set a soil cleanup goal for the system based on a total chemical removal rate of less than 10 pounds per day (4.5 kg/day). In other words, when the SVE system stopped removing at least 10 pounds (4.5 kg) of total contaminants per day, the CRWQCB and EPA would consider the soil remediated. This approach was based on risk assessment studies that indicated no significant threats to human health or the environment would be present at or below the 10-pounds-per-day (4.5-kg/day) level.

After seven months of operation, the SVE system had reduced TCA concentrations to 416 mg/kg and DCE concentrations to 2.2 mg/kg. After 16 months of operation, the SVE system had met the cleanup goal and was removing less than four pounds per day (1.8 kg/day) of contaminants. Approximately 16,000 pounds (7,258 kg) of solvent had been removed from the soil, with the most recovery occurring within the first two months. In April 1990, the EPA and CRWQCB agreed with Fairchild that cleanup goals had been met and gave the company permission to

shut down the SVE system. Capital and operating costs for the installation and maintenance of the system totaled about \$4 million.

One of the reasons the Fairchild SVE operated so successfully was that, prior to its installation, a pilot test was run. Such a test consists of the installation, operation, monitoring, and maintenance of a mini-SVE system. One or two extraction wells are drilled and equipped and then operated at different wellhead vacuums over a few weeks or months. ROIs are measured in the field, along with the amount of contaminants being captured by the system. Using these data, more efficient final system design specifications can be developed for the full-scale operation.

The environmental problems at Fairchild's San Jose facility were severe, and SVE was not the only remedial solution implemented at the facility. A slurry wall, connected to an underlying layer of clay, was installed around the perimeter of the site to contain the most heavily contaminated groundwater. Groundwater collected by recovery wells installed behind this slurry wall was pumped to an on-site air-stripping treatment system, and then reinfiltred to help flush remaining contaminants out of the soil. Contaminated groundwater from selected off-site areas also was recovered and treated by the on-site system. These cleanup actions significantly reduced the size of the contaminant plume and the concentration of organic compounds that were present.

For business reasons related primarily to the influx of less expensive chips from Asian manufacturers, Fairchild closed the San Jose plant in 1983. The property has been redeveloped for commercial nonmanufacturing uses, but a legacy of its past remains permanently fixed in the public record. Both EPA and CRWQCB required that the site owners, before selling, include a notice in the property deed alerting prospective buyers that contamination was present in the soil on the site and that its groundwater cannot be used for potable purposes. The deed notice also requires that any future use of the site not interfere with ongoing cleanup activities. This was one of the early uses of an institutional control, a way that allows environmentally damaged property to be returned to productive use but safeguards investors, developers, and end users (workers, shoppers, visitors, etc.) by ensuring that redevelopment occurs in a manner that is protective of public health and the environment.

*See also* BENZENE; DCE; ORGANIC POLLUTANTS; PCE; TCA; TOLUENE; UNDERGROUND STORAGE TANK; VOLATILE ORGANIC COMPOUND; WELLS; XYLENE.

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**Feed Materials Production Center Fernald, Ohio (1989–2007) Water Pollution, Soil Pollution** In late January 2007, one of the largest, most extensive environmental cleanup and restoration projects ever carried out by the Department of Energy was officially declared complete. The beginning of this 18-year \$4.4-billion effort can be traced to a decision made by the Atomic Energy Commission in the late 1940s to build a single facility that could process and refine uranium metal. Until then, uranium processing was carried out at separate facilities in New York, Missouri, and Ohio. At this time in history, the United States was deeply embroiled in the cold war arms race with the Soviet Union, and the development, production, maintenance, and testing of nuclear weapons were critical components of the national defense strategy.

Pure uranium is a dense, silvery white metal that is malleable, ductile, and slightly paramagnetic. The uranium that occurs in minerals and rocks, called natural uranium, is made up of three principal isotopes, uranium 238 (99.3 percent), uranium 235 (0.71 percent), and a trace of uranium 234. Uranium 235 is fissionable; that means that if it is bombarded with slow neutrons, a self-sustaining chain reaction can be produced that releases energy. In order for natural uranium to be useful in a weapon or an energy producing reactor, it must first be enriched

to greater than 90 percent uranium 235. Prior to enrichment, the uranium metal has to be molded or formed into specific shapes and sizes.

## BACKGROUND

The Atomic Energy Commission (AEC) was the first federal agency in charge of the United States nuclear weapons and energy programs. The AEC located its uranium metal processing facility in the small farming community of Fernald, Ohio, about 20 miles (32.2 km) northwest of Cincinnati. Fernald had the perfect combination of available inexpensive, flat-lying land; a skilled workforce; nearby rail access; and an almost inexhaustible supply of freshwater. Using its power of eminent domain, the federal government condemned and purchased 1,050 acres (425 ha) of farmland for the construction of a critical national defense installation, the Feed Materials Production Center, or FMPC.

Operational in only five months, by 1951, the first on-site building, the Pilot Plant, began to test methods to develop high quantities of high-purity uranium ingots (bars), derbies (canisters), billets (slabs), and fuel cores (rods) for use in nuclear weapons and nuclear reactors. Eventually, production activities were centered on a 14-acre (5.7-ha) section of the property. From the mid-1950s through the early 1960s, almost 12,000 tons per year (10,886 metric tons per year) of uranium metal was processed. Expanding to 10 major buildings or plants, FMPC



**Waste storage tanks, Feed Materials Production Center near Fernald, Ohio, 2001 (DOE Photo)**

employed 2,900 people and operated 24 hours per day, seven days per week.

Uranium ore was delivered by rail, sampled and classified by uranium concentration, and transferred to silos or drums. The ore then was converted to high-purity uranium trioxide by digestion in acid, chemical extraction, and denitrification. Next, the uranium trioxide was chemically reduced to uranium dioxide by treating it with hydrogen. This material, called brown oxide, then was reacted with anhydrous hydrogen fluoride to form uranium tetrafluoride, or “green salt.” The next step in the processing cycle was to transfer the green salt to Plant 5 or 6, the metal production plants. It was these large hangarlike buildings that formed the heart of FMPC. Fed into industrial furnaces, the green salt was mixed with magnesium and thermally treated to form uranium metal derbies. These derbies then were loaded into graphite molds, melted, and poured into specified shapes (ingots, bars, etc.). Finished cutting and milling were done in other areas of FMPC or sometimes shipped to other facilities and then returned before the final product was sent to the Department of Energy (DOE) facility in South Carolina or Washington State for enrichment. FMPC also processed thorium and accepted uranium from other facilities for recycling into its own production operations. These processes produced 187,400 tons (170,000 metric tons) of uranium metal for more than almost 40 years and were an essential part of the U.S. nuclear defense system.

### POLLUTION OF THE SITE

National Lead of Ohio (NLO), a wholly owned subsidiary of National Lead and a major government contractor, ran FMPC for most of its operational life. Working under tight security and with a high level of secrecy during its production years, NLO received numerous awards for worker safety, manufacturing efficiency, and cost-effectiveness at FMPC but, as in many of its private sector industrial counterparts, not much attention was paid to environmental protection.

During the late 1970s and early 1980s, awareness of environmental issues grew, and the lessening of cold war tensions significantly reduced the need for facilities such as FMPC. As the veil of secrecy that had surrounded—and, to a certain extent, shielded—the operational history at FMPC began to be lifted, it became apparent that facility operations had resulted in several serious environmental and public health consequences. Uranium metal and other site-related contaminants were present in

soil, groundwater, and buildings on the site, and, in several cases, uranium in the groundwater had migrated to off-site areas, including private wells being used for potable water.

The demise of FMPC began in 1984 when the DOE announced that almost 300 pounds (136.1 kg) of uranium oxide had been released into the atmosphere from one of the dust collectors in Plant 9, the building where casting of oversized uranium ingots was performed. Following shortly was a second disclosure by DOE that groundwater from three nearby residential wells contained uranium at levels above water quality standards and that this contamination had been known to be present since at least 1981. Finally, in 1986, DOE admitted that there had been an unauthorized release or venting of radioactive materials from two waste storage silos and that a dangerous crack had been discovered in a Pilot Plant process vessel.

Within weeks, stories were aired on *60 Minutes* and *20/20*, and newspaper and television reports were being widely distributed about FMPC operations in Britain, Canada, Japan, and Germany. As public concerns grew, the U.S. Environmental Protection Agency (EPA) and Ohio Environmental Protection Agency (OEPA) launched their own environmental investigations into FMPC waste management practices. Over the next several years, the extent of the environmental and potential public health impacts became more frightening.

### A LEGACY OF POLLUTION

For many years, FMPC had difficulty with the effective maintenance and operation of its dust collectors. They were designed to trap and remove airborne particles of uranium released during heating and milling operations. The dusts and fumes were acidic and the baghouses and cyclones used for particulate control tended to corrode and become inoperative. Once released, the uranium dust followed local wind patterns and was deposited as fallout and precipitation washout both on FMPC property as well as on nearby farmlands and pastures. Almost 1 million pounds (453,592 kg) of uranium dust was thought to have been released into the atmosphere by FMPC.

The Great Miami River and its tributaries flow across a series of porous and permeable glacially derived sands and gravels that recharge the Great Miami Aquifer. This aquifer provides drinking water to more than 500,000 people in a 15-county region of Ohio. The Great Miami is one of the 10 largest rivers in Ohio and merges with the Ohio River near Cincinnati. The Great Miami River is an important drinking water resource in its own

right, but underlying FMPC, and extending across much of this part of southwest Ohio is a complex, buried-valley aquifer system that is recharged, in part, by infiltration of water from the Great Miami River and its tributary, the Little Miami River. This water-bearing zone, called the Great Miami Aquifer, is an EPA-designated sole-source aquifer; that means that it is the primary source of drinking water for almost 2 million people who live above it. The aquifer is present in bedrock valleys carved from Silurian and Ordovician limestone and shale, and then filled with coarse-grained sand and gravel. Wells tapping the sand and gravel deposits can produce more than 1,000 gallons per minute (3,785 L per minute), and water can be found as close as 20 feet (6.1 m) below the surface.

Discharges of uranium from FMPC's wastewater treatment plant resulted in the contamination of surface water and sediments within the Great Miami River. A total of 200,000 pounds (90.7 metric tons) of uranium may have been discharged to the Great Miami River and a tributary (Paddy's Run Creek) by surface runoff and through FMPC's wastewater treatment plant.

In addition, FMPC opened six waste pits on its property for disposal of off-spec products, sludge and debris containing residual amounts of uranium, as well as other types of chemical waste. Although it was buried in a thick layer of glacial clay that covered most of the site, the cover on these waste pits allowed the infiltration of rainwater. The pits filled up with water (the "bathtub effect") and either overflowed or leaked into Paddy's Run, an adjacent creek. The contaminated runoff then washed downstream and either discharged into the Great Miami River or seeped into the underlying aquifer. Groundwater contamination also was present underlying many of the FMPC process buildings.

### THE CLEANUP

To alleviate public concerns, DOE replaced NLO as the operating contractor in 1986 with the Westinghouse Material Company of Ohio, a subsidiary of Westinghouse Electric Corporation. DOE also entered into an agreement with the EPA to begin a comprehensive set of site investigation and remedial activities. These measures, however, were too little and too late. The pollution problems coupled with a decline in demand for the material it produced, resulted in the final closure of the facility in 1989 and the cessation of all production operations.

To facilitate regulatory interactions and procedures with the EPA and OEPA, FMPC was added to the National Priorities List by the EPA as a Super-

fund site in 1989, and a series of short-term, interim remedial measures were implemented designed to address the highest-risk areas while more comprehensive studies began to develop longer-term remedial solutions. The name of the site was changed in 1991 to the Fernald Environmental Management Project (FEMP) to indicate the new mission of site operations, and, although it would take many years, the trust and confidence of most local residents and regulatory agency personnel in the objectives and methodologies of the cleanup were reestablished.

Over the next 18 years, DOE and its contractor, Fluor Fernald, demolished more than 100 on-site structures, removed millions of tons of highly contaminated soil and radioactive wastes, and constructed a special 110-acre (44.5-ha) secure disposal area to hold low-hazard materials that do not pose a significant ecological or public health risk safely. A recovery and treatment system was installed to contain and remediate the contaminated groundwater plume present in the Great Miami Aquifer. This approximately 30-well system will operate into the next decade, extracts 4,000 gallons of groundwater per minute (15,142 L per minute) from the Great Miami Aquifer, and discharges the treated water to the Great Miami River. As part of remedial efforts, a public water supply system was extended to those residents whose supply wells had been contaminated by discharges from FMPC. Groundwater monitoring will continue to be performed in order to verify the effectiveness of the extraction and treatment system until uranium concentrations are reduced to acceptable levels.

### THE AFTERMATH

Fernald area residents who sought compensation for emotional distress and decreased property values filed a class action lawsuit against DOE and NLO in 1984. Without admitting fault or negligence, DOE settled the suit in 1989 for \$78 million for commercial and private property within a five-mile (8.1-km) radius of FMPC. NLO suffered no penalty because the federal government was required, under its operating contract with NLO, to protect, or indemnify, them from these types of lawsuits and claims.

The final end use of the property, however, was intended to underscore the seriousness of DOE's commitment to Fernald's environmental restoration. Rather than some sort of industrial or commercial use, DOE has attempted to restore this former 1,000-acre (405-ha) parcel to its preuse, natural condition. A total of 400 acres (162 ha) of woodlots was designed and cultivated, 330 acres (133.6 ha) of seeded prairie, more than 140 acres (56.7 ha) of open water and



wetlands, and 30 acres (12.1 ha) of savanna. The FEMP is now an undeveloped park, designed to provide a venue for the viewing of wildlife with an education and community center intended to enhance the understanding of Ohio's ecology and environment, including the history and operation of FMPC.

*See also* AQUIFER; GLACIAL DEPOSITS; RADIATION; RADIOACTIVE WASTE; SOIL POLLUTION; SUPERFUND SITES; WATER POLLUTION; WELLS.

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**Floridan Aquifer** The Floridan Aquifer is one of the major regional aquifers in the United States. It covers the entire state of Florida and parts of Alabama, Georgia, South Carolina, and even the edge of Mississippi. Its great thickness and underground cave system allow it to store immense quantities of groundwater. The karst topography, however, produces a pronounced environmental hazard in that agricultural runoff and industrial effluence enter the groundwater system directly through sinkholes and are not filtered naturally. Although it is a great source of water, the Floridan Aquifer is delicate and subject to a number of environmental problems.

#### DIMENSIONS AND UNITS

The Floridan Aquifer underlies an area of about 100,000 square miles (256,000 km<sup>2</sup>) within the Atlantic and Gulf Coast Coastal Plain. It is generally thinner to the north, where it is no more than 250 feet (77 m) thick in Georgia and South Carolina. To the south in Florida, it is up to 3,400 feet (1,046

m) thick, especially within the Gulf Trough, a fault-bounded graben.

The Floridan Aquifer is all limestone that mainly ranges in age from about 65 million years to about 20 million years old. It is composed of three units in most places, the Upper Floridan Aquifer, the middle confining unit, and the Lower Floridan Aquifer. The middle unit prevents mixing of water between the upper and lower aquifers. Through most of the area, the upper unit is overlain by a sequence of sand, clay, and limestone that ranges from a few feet thick in central Florida to more than 250 feet (77 m) thick in northeastern Florida and southeastern Georgia. This unit confines the upper aquifer in several large areas, allowing it to become pressurized. In southern Florida, there is a unit in the lower aquifer called the boulder zone. It is formed by a huge cave system with a vertical height of up to 90 feet (28 m). This zone is very deep, up to 3,400 feet (1,046 m) below sea level.

#### WATER FLOW

Recharge of the Upper Floridan Aquifer occurs in generally unconfined upland areas with good drainage, primarily along its northern edge but also in northwestern Florida. Poorly developed streams and abundant sinkholes provide the pathways to recharge. Where the overlying confining layer is 100 feet (30 m) thick or more in northeastern Florida and most of Georgia, recharge is poor.

Natural discharge from the Upper Floridan Aquifer occurs from the plentiful springs. There are as many as 33 first-order springs in Florida with discharge in excess of 100 cubic feet (3 m<sup>3</sup>) per second, or 64.6 million gallons (245 million L) of water per day. In all, there are about 800 natural springs with about 90 percent of them in Florida. Total discharge from these abundant springs is estimated at eight billion gallons (30 billion L) per day.

The Lower Floridan Aquifer is not well known because it is too deep in many areas. The water movement is considered sluggish in most places except where it is connected to the upper aquifer. It is in these areas that most recharge takes place. Discharge is only through wells and is sparse in central and northern Florida. In most areas, only the upper aquifer is drilled in order to provide water.

#### WATER USAGE

The Floridan Aquifer was first recognized for its potential as a source for water in the 1930s. By the 1940s, it was regularly drilled, and its use was continuous and increasing. By 1950, consumption

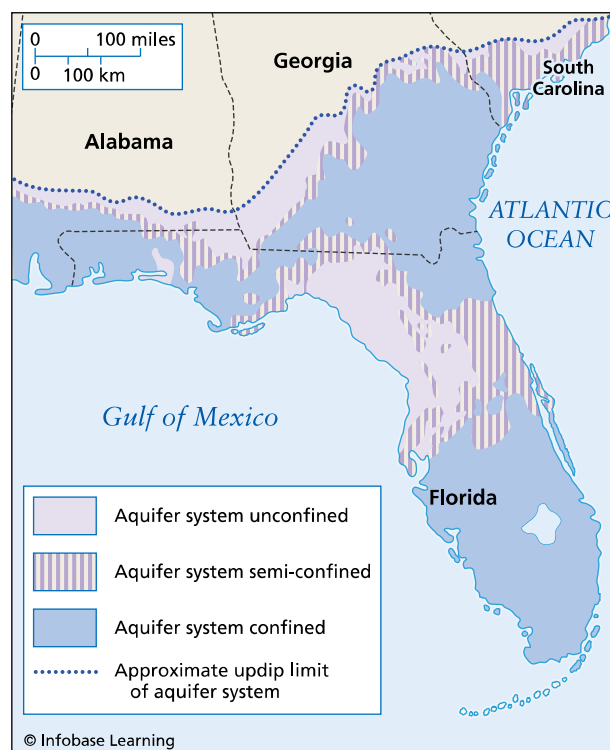
was 630 million gallons (2,394 million L) per day including 90 million gallons (342 million L) per day for irrigation. Between 1950 and 2000, the water withdrawals from the Floridan Aquifer increased by more than 500 percent. In 2000, it is estimated, 4,020 million gallons (15,275 million L) per day was withdrawn from the Floridan Aquifer from producing wells. About 78 percent of this consumption, or about 3,125 million gallons (11,875 million L) per day, was in Florida, whereas it was 825 million gallons (3,135 million L) per day in Georgia, 63 million gallons (239 million L) per day in South Carolina, and 7 million gallons (27 million L) per day in Alabama. Mississippi did not consume any water from the aquifer. About 90 percent of the water consumption was from the upper aquifer. About 8.2 million people consumed the water withdrawn for public water supplies, whereas about 1.6 million people consumed water from private wells.

### PROBLEMS WITH WATER QUALITY AND QUANTITY

With all of this consumption, it is no surprise that the water table is rapidly declining in the shallow Floridan Aquifer. In southern Georgia and northeastern Florida, water levels have declined about 0.3–0.5 foot (9–15 cm) per year since 1950. In the Florida Panhandle, levels dropped 100 feet (31 m) between 1950 and 2000, forcing several towns to relocate their well fields. This decrease in water has dropped lake levels, dried up wetlands and swamps, and reduced the flow rates in many springs or stopped them completely.

The reduction in quantity has also had a negative impact on quality. In many coastal areas such as Hilton Head, South Carolina, and Pensacola, Florida, among others, the withdrawn freshwater has been progressively replaced with salt water from the ocean. Previously, the vast freshwater flow took it right to the coast. Saltwater incursion in many areas is impacting private and public wells and threatens to disrupt the tourism industry. Wells have to be drilled inland to compensate, but the draw keeps pulling the salt water farther inland as well.

Pollution of the aquifer from human sources is rampant. In many areas, sinkholes form an open passage from surface water to groundwater. Dry sinkholes are commonly used as dumps in rural areas, where rainwater leaches through waste to deliver leachate directly into the groundwater system. Flooded sinkholes form lakes and ponds that are desirable building locations. Overflow from septic systems and runoff carrying fertilizers and pesticides from lawn and landscaping flow into these water bodies, which are



**Map of the Floridan Aquifer system in Alabama, Georgia, Florida, and South Carolina**

directly connected to the groundwater system. Agricultural runoff also carries pesticides and fertilizers into the sinkholes. As industry has followed the population boom in Florida and Georgia, it too contributes industrial chemicals to the mix. The water quality in the Upper Floridan is degrading at a rapid pace. Pesticides, herbicides, and fertilizer are now detectable in most of the water taken from the upper aquifer. Some towns are starting to draw from the lower aquifer, but it is saline and not potable through much of the area. This situation will worsen as consumption increases.

The Floridan Aquifer flows groundwater through a cave system. Normally, groundwater is purified by filtration through the small grains of common sediments. Caves transmit groundwater with virtually no filtering or chemical purification at all. They are simply large pipes. For this reason, the Floridan is particularly sensitive to pollution.

*See also* AQUIFER; COASTAL PLAIN DEPOSITS; KARST; PESTICIDES; SALTWATER INCURSION.

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**formaldehyde** Formaldehyde is one of the most widely recognized industrial chemicals, both in terms of the name and the sickly sweet smell and because it is used as a preservative for biological specimens such as fetal pigs and frogs. It is also widely recognized as a preservative for recently deceased people so that the corpse will not begin to decay before the funeral. Even though it is best known for these uses, they are minor in comparison to the industrial use of formaldehyde. It is from these sources that formaldehyde may be a pollutant. The most recent example occurred when the trailers issued to survivors of Hurricane Katrina by the Federal Emergency Management Agency (FEMA) in 2005 and 2006 began to have unhealthy levels of formaldehyde detected in them. The reason was that it was evaporating from the construction materials inside the trailers in the hot southern sun. Indeed, formaldehyde's greatest threat is as an indoor air pollutant that emanates from industrial products.

Formaldehyde is also known as methanal, methylene oxide, oxymethylene, methylaldehyde, and oxomethane. Formaldehyde is available in the United States as its cyclic trimer under the name trioxane and as paraformaldehyde. Formaldehyde has been found in only 26 of the first 1,428 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List). It is the widespread extent and danger as an indoor air pollutant that

led it to be ranked number 244th of the worst 275 pollutants on the 2007 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USE, AND PRODUCTION

Formaldehyde is an organic compound and a volatile organic compound (VOC) that is naturally occurring and synthetically produced for industrial purposes. In pure form, it is a colorless, flammable gas at room temperature with a pungent, distinct odor. Most formaldehyde is available as a solution, known as formalin, which contains 30–50 percent formaldehyde with 0.5–15 percent methanol. Another available form is trioxane, a crystalline solid with a chloroformlike odor. The primary use of formaldehyde is industrial in the production of chemical resins (57 percent), acetylenic chemicals (12 percent), methylene diisocyanate (6 percent), pentaerythritol (5 percent), urea-formaldehyde concentrates (4 percent), hexamethylenetetramine (4 percent), and miscellaneous products such as chelating agents, nitroparaffin derivatives, and textile treatments (12 percent). These and other formaldehyde-related chemicals are used in the production of fertilizer, paper, plywood, sugar, and well-drilling fluids. They are also used in iron foundries, in agriculture as a preservative for grains and seed dressings, in the rubber industry in the production of latex, in leather tanning, in wood preservation, and in photographic film production. Formaldehyde is also used in relatively small quantities for preservation and disinfection. These include disinfecting hospital wards, homes, ships, storage houses, utensils, and clothing. It is used for preserving and embalming biological specimens; for sterilization of soil; as an insecticide, germicide, and fungicide; and as an antibacterial agent in soaps, shampoos, deodorants, hair preparations, lotions, cosmetics, mouthwashes, and nail products.

Formaldehyde has been produced commercially since the early 1900s and has consistently ranked among the top 25 highest-volume chemicals produced in the United States in recent years. Annual production was 1.87 billion pounds (848,000 metric tons) in 1960 but increased to 11.3 billion pounds (5.14 million metric tons) by 1998. Formaldehyde imports to the United States were about 2.5 million pounds (1.1 million kg) in 1978, 16.2 million pounds (7.4 million kg) in 1983, and 8.5 million pounds (3.9 million kg) in 1985. Imports then increased to 87 million pounds (39.5 million kg) in 1994, 140 million pounds (63.6 million kg) in 1997, and 62 million pounds (28.2 million kg) of formaldehyde and 18.3 million pounds (8.3 million kg) of paraformal-

dehyde in 2000. In contrast, exports were 25 million pounds (11.4 million kg) in 1994 and 17.4 million pounds (7.9 million kg) in 2000.

### ENVIRONMENTAL EXPOSURE AND FATE

Formaldehyde is naturally produced in small amounts in the human body as a part of normal metabolism. A major source of formaldehyde exposure is smog in the lower atmosphere. Exhaust from cars without catalytic converters or those using oxygenated gasoline contains formaldehyde. Automobile exhaust is a major source of formaldehyde in ambient air. In indoor air, formaldehyde is in tobacco smoke and is emitted from gas cookers and open fireplaces. Cigarettes may contribute as much as 10–25 percent of the indoor exposure. It is also used as a preservative in foods, such as some types of cheeses, dried foods, and fish. Some people are exposed to higher levels of formaldehyde if they live in a new mobile home, as formaldehyde is given off as a gas from the manufactured wood products used in these homes.

By far, most formaldehyde is released to the air. Formaldehyde dissolves easily in water, but it does not last a long time because it evaporates or is broken down by microorganisms and is not commonly found in drinking water supplies. According to the EPA Toxic Chemicals Release Inventory (TRI), the annual environmental releases of formaldehyde totaled 17.2–24.9 million pounds (7.8–11.3 million kg) between 1988 and 1999 with the majority (50–66 percent) released to the atmosphere. Releases for 1999 were approximately 24.2 million pounds (11 million kg) from 849 facilities. In 2006, total releases were 21,492,962 pounds (9,769,528 kg).

### HEALTH EFFECTS FROM EXPOSURE

There are several adverse health effects from exposure to formaldehyde. Symptoms from acute exposure at low levels include irritation of the eyes, nose, and throat, along with increased tearing. Severe pain, vomiting, coma, and possible death can occur after drinking large amounts of formaldehyde. Skin can become irritated by contact with a strong solution of formaldehyde. There are not any specific effects from long-term chronic exposure to formaldehyde except an increased incidence of cancer.

Laboratory rats exposed to high amounts of formaldehyde in air for life had an increased chance of developing nose cancer. Some studies of humans exposed to lower amounts of formaldehyde in workplace air developed more cases of cancer of the nose, sinuses, and throat (nasopharyngeal

cancer) than expected. There is also some evidence for excess risk for brain cancer, largely seen among morticians. Rats exposed to high levels of formaldehyde in drinking water had increased incidences of leukemia and forestomach and gastrointestinal tract tumors.

As a result of these findings, the U.S. Department of Health and Human Services (USDHHS) determined that formaldehyde may reasonably be anticipated to be a human carcinogen. The International Agency for Research on Cancer (IARC) determined that formaldehyde is a probable carcinogen for humans, and the EPA agreed.

### REGULATIONS ON HUMAN EXPOSURE

As a result of these adverse health effects, especially the potential for causing cancer, several federal agencies have imposed limitations on human exposure to formaldehyde. The EPA does not have regulations on formaldehyde in drinking water under the Safe Drinking Water Act because it rarely occurs in water. They do, however, set regulations for manufacturers and inspection stations on how much formaldehyde can legally be produced from automobile exhaust. They also require that any release of 100 pounds (45 kg) or more must be reported to the National Response Center. The Food and Drug Administration (FDA) has regulations about the use and quantity of formaldehyde in foods, soaps, and cosmetics. The Occupational Safety and Health Administration (OSHA) established the permissible exposure limit (PEL) at 0.75 part per million (ppm) in air for any eight-hour period and a 15-minute short-term exposure limit (STEL) at 2 ppm. The National Institute of Occupational Safety and Health (NIOSH) set a limit for occupational exposure of 0.016 ppm for any eight-hour period and a 15-minute ceiling limit of 0.1 ppm. The NIOSH immediately dangerous to life and health (IDLH) threshold is set at 20 ppm. The NIOSH National Occupational Exposure Survey taken from 1981 to 1983 found that 1,329,332 workers were potentially exposed to formaldehyde in the workplace.

*See also* AIR POLLUTION; INDOOR AIR POLLUTION; ORGANIC POLLUTANTS; SUPERFUND SITES; VOLATILE ORGANIC COMPOUND.

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**Formerly Utilized Sites Remedial Action Program (FUSRAP) Saint Louis, Missouri 1957–present Soil Pollution** The Formerly Utilized Sites Remedial Action Program (FUSRAP) is a Department of Energy (DOE) initiative that is managed and performed by the U.S. Army Corps of Engineers. FUSRAP was created to address radiological contamination left behind at 46 locations throughout the United States from the early nuclear weapons and energy programs overseen by the Manhattan Engineering District (MED) and Atomic Energy Commission (AEC). Both the MED and AEC were predecessor organizations of the DOE, which currently manages the nation's nuclear weapons and military nuclear energy production activities.

### BACKGROUND

More commonly known as the Manhattan Project, MED was the joint military and scientific effort carried out by the United States, with support from both Canada and the United Kingdom, to develop a nuclear weapon using uranium 235 and plutonium 238. Taking its name from the Manhattan Engineering District of the U.S. Army Corps of Engineers, the administrative center for overall program management, research and production activities were scattered across some 30 sites around the United States. Three top secret scientific "cities," including Hanford, Washington; Los Alamos, New Mexico; and Oak Ridge, Tennessee; were built to support full-scale fabrication of the weapon and its related components. Significant contributions to this wartime program were made at sites in Illinois, Cali-

fornia, Utah, and Colorado. By 1945, shortly before exploding the first of its three fission bombs, MED was responsible for 130,000 employees, had spent more than \$3.2 billion (in 2010 dollars), and was using almost 20 percent of the electricity generated in the United States.

At the end of World War II, the development and use of nuclear technology were transferred from military to civilian control by the establishment of the AEC. Originally charged with making sure nuclear weapons could be used effectively in defense of the country, the AEC also was responsible for encouraging the development of peacetime uses of commercial nuclear power, tools, and by-products. The AEC established the national laboratory system and promulgated regulatory programs to protect the public from the hazards of nuclear material use.

The AEC's dual mission, to control the use and application of nuclear technology tightly while promoting its development, led to severe criticism that the agency was either too protective, developing regulations and restrictions that inhibited beneficial commercial applications of nuclear energy, or not protective enough, establishing radiation protection standards that were too lax in the areas of nuclear reactor safety, power plant siting, and environmental protection. As criticism of the agency grew, Congress abolished the AEC in 1974 and divided its programmatic objectives between the newly created agencies: the Nuclear Regulatory Commission (NRC), now charged with overseeing the commercial use of nuclear material, including commercial power plants, and the Energy Research and Development Authority (ERDA), which eventually became the DOE. Today, the DOE is responsible for operating and maintaining the military use of nuclear materials, as well as ensuring the energy security of the United States. Similarly to MED programs, the AEC programs that were intended to advance the scientific understanding and commercial use of nuclear materials resulted in the contamination of buildings, soil, and groundwater at sites in New York, New Jersey, Ohio, Iowa, and numerous other locations.

Most of the contaminated MED and AEC sites were cleaned up to a certain extent, but the public health and radiation protection standards that were applicable in the 1950s and 1960 do not meet those developed in the 1980s and 1990s. The residual amounts of radioactivity present at these sites needed to be addressed, and, more importantly, in many cases contamination had been spread to other locations, either through building demolition and intentional relocation of contaminated materials to local landfills or by such natural processes

as erosion or surface water runoff. To identify, manage, and address these former MED and AEC commercial and governmental research, development, and manufacturing sites, DOE established FUSRAP in 1974. In 1997, Congress transferred the responsibility for the administration and execution of FUSRAP from DOE to the U.S. Army Corps of Engineers (USACE).

Typical contaminants encountered at FUSRAP sites include low concentrations of uranium, thorium, and radium, with their related decay products. Mixed wastes of hazardous chemicals and radiological wastes also are present at some FUSRAP sites. Although none of the currently identified FUSRAP sites represents an immediate public health threat because the levels of radioactive materials present on them are low, their cleanup is an important step in addressing local community concerns and, in many cases, allowing for the productive reuse of often blighted and abandoned property. In addition, contaminants at these sites will remain radioactive for thousands of years, and long-term, uncontrolled exposure to radiation is not consistent with any public health goal. Remediation has been completed at about half of the FUSRAP sites, and cleanup activities are either under way or being planned for the remaining properties. One part of the country that has benefited from FUSRAP cleanup activities is the area in and around Saint Louis, Missouri.

### THE CONTAMINATION

On December 2, 1942, the following coded message was received at the White House: “The Italian navigator has landed in the new world, the natives are friendly.” The Italian Navigator was Enrico Fermi, and the message signaled that his team of physicists and engineers at the University of Chicago had initiated the first successful self-sustaining nuclear chain reaction in a small reactor called Chicago Pile-1 beneath the bleachers at Stagg Field, the university’s abandoned racquets court. This reaction was powered by uranium oxide produced at the 45-acre (18.2-ha) Destrehan Street Refinery and Metal Plant, the chemical plant and metalworking facility in an industrial area near downtown Saint Louis. The plant was later renamed the Mallinckrodt Chemical Works. Three brothers, Edward, Otto, and Gustav Mallinckrodt, founded the company in 1867 as a manufacturer of fine chemicals for pharmaceuticals. It has since grown to be one of the world’s largest firms, specializing in inhalation therapies, medical imaging products, and prescription medications.

MED contracted Mallinckrodt to process uranium and radium ores to produce the fissionable

materials needed for the development of a nuclear weapon. It was the material from the Destrehan Street plant that was in the atomic bombs used on Nagasaki and Hiroshima. In 1957, AEC ordered Mallinckrodt to cease operations at its downtown location, but between 1942 and 1957, the plant had processed more than 50,000 tons (45,359 metric tons) of uranium and radium ores. Although it was decontaminated after the war according to the 1950-era radiation protection standards in effect at the time, radioactive residuals remained, and this location became one of the first FUSRAP-designated properties, known as the Saint Louis Downtown Site.

In 1946, shortly after the end of the war, with the production of nuclear weapons proceeding at breakneck pace, MED purchased 21 acres (8.5 ha) north of the Saint Louis airport for the storage of process by-products containing radioactive residuals from the downtown Saint Louis Mallinckrodt plant. Most of the wastes and residues are stored on open ground, but some contaminated materials and scrap are buried at the western end of the property as well as other parts of the site. Adjoining parcels became contaminated when radioactive materials were washed or blown off the uncovered waste piles. This storage area became the second Saint Louis FUSRAP location, named the Saint Louis Airport Site.

### CLEANUP ACTIVITIES AND CONTAMINATION

In the early 1960s, uranium processing residues and wastes stored at the Saint Louis Airport Site, which also contained several other types of valuable minerals such as copper, were sold by AEC to Continental Mining and Milling Company for reclamation. Continental moved these materials to its reclamation facility in Berkeley, Missouri, but sloppy handling and transfer procedures resulted in the spread of contamination along the haul routes. Those parcels impacted by the relocation of the Saint Louis Airport Site residues became the third FUSRAP designated area, the Saint Louis Airport Vicinity Properties. The reclamation plant where the wastes were shipped and stored was designated the fourth FUSRAP location, the Hazelwood Interim Storage Site.

Once the residuals were relocated to Hazelwood, the existing structures at the St. Louis Airport Site were demolished and buried. They included about 60 truckloads of scrap metal and building debris, along with a vehicle. Up to three feet (1 m) of clean fill (soil) was spread across the surface, in order to meet acceptable radiation exposure levels at the

surface. After the waste piles were removed and remaining contaminated materials buried, the AEC transferred the property to the Saint Louis Airport Authority for reuse. Before this, however, the last of the on-site waste, made up primarily of uranium coprecipitated with barium sulfate, was mixed with topsoil and sent to the Saint Louis County landfill for disposal.

In 1976, the NRC surveyed the Hazelwood Interim Storage Site and found residual uranium concentrations, thorium concentrations, and gamma radiation exposure levels present at concentrations above guidelines for release of the property for unrestricted reuse. This triggered a series of studies and investigations over the next two years that found similar levels of radioactivity at the Saint Louis Airport Site and the associated vicinity properties, including several drainage ditches and Coldwater Creek near the Hazelwood facility designated the Latty Avenue Vicinity Properties.

Another FUSRAP site directly related to the Saint Louis properties is the Madison Site. This is an active aluminum and magnesium metal extruding facility across the Mississippi River from the Saint Louis Airport Site, in Madison, Illinois. Formerly a division of Dow Metal Products, in the late 1950s and early 1960s, Mallinckrodt had subcontracted the Madison plant to perform its uranium extrusion and rod-straightening operations. A 1989 survey indicated that two of the buildings used in this process contained low-level radioactive contamination in dust that had settled on beams and other overhead surfaces. In 2000, the uranium-contaminated dust was vacuumed from overhead structures over a 12-day period. By mid-July, independent surveys confirmed that the Madison Site had been successfully decontaminated. A total of 40 cubic yards (30.6 m<sup>3</sup>) of waste was packaged and shipped to a licensed out-of-state disposal facility. In 2002, the buildings at Madison subsequently were removed from the list of FUSRAP sites. Cleanup of the other St. Louis FUSRAP sites is not as simple, as remedial solutions are essentially limited to excavation and eventual transfer to a final, secure disposal site.

In 1984, the DOE made an attempt to convert the Saint Louis Airport Site into a permanent disposal facility, or cell, for all FUSRAP-related wastes. This plan met with strong resistance from both local area residents and city government, who refused to turn over the title of the property to the DOE. As the site characterization studies continued, and pressure for action grew, the St. Louis FUSRAP sites were added to the National Priorities List as Superfund sites. At the Saint Louis Downtown Site, between 1995 and 2003, the USACE

directed the excavation and out-of-state disposal of almost 64,000 cubic yards (50,338 m<sup>3</sup>) of contaminated soil and debris. At one point, excavation had to be temporarily halted when unexploded Civil War vintage ordnance was discovered buried in one area of the property. In addition, 60 buildings were decontaminated and demolished.

The Saint Louis Airport Site was the largest repository of FUSRAP-related wastes. In places, contamination extended to almost 20 feet (6.1 m) below the ground surface across the 21-acre (8.5-ha) property. Between 1997 and 2002, more than 200,000 cubic yards (152,911 m<sup>3</sup>) of contaminated soil and debris was removed and shipped to a permitted, out-of-state disposal facility. USACE also has worked to stabilize remaining impacted areas through improvements to site drainage and soil cover.

The Hazelwood Interim Storage Site (HISS) and the associated Latty Avenue Vicinity Properties (Latty VPs) are within a few miles of the Saint Louis Airport Site. Thorium and radium contamination was present in soil up to 18 inches (45.7 centimeters) below the surface at levels in excess of federal guidelines. During redevelopment of the site by its current owner, 13,000 cubic yards (9,939 m<sup>3</sup>) of contaminated material was excavated and stockpiled on the eastern side of the site. Another 14,000 cubic yards (10,704 m<sup>3</sup>) was recovered from cleanups along Latty Avenue in 1984 and 1985. By 2001, more than 24,000 cubic yards (18,349 m<sup>3</sup>) of material was removed from the Hazelwood site and sent in covered gondola railcars for disposal to a permitted out-of-state disposal facility.

Remedial activities are ongoing at the Saint Louis FUSRAP sites, as well as other, similar places around the country, and the ultimate cost of the cleanups has been estimated at \$2 billion. The real cost of America's nuclear arms race cannot be tallied until the final FUSRAP site is released for unrestricted reuse.

*See also* RADIATION; RADIOACTIVE WASTE; RADIUM; SUPERFUND SITES.

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clouds appear and slowly build thicker and lower. Rain begins as drizzle and slowly intensifies, lasting up to several days, and clears slowly.

As in the cold front, the rain from warm fronts effectively removes particulate from air. These systems, however, typically do not include as much wind unless closely associated with a low-pressure system. With the warm humid air that builds behind the front, buildup of gaseous pollutants in stagnant conditions may occur soon after passage.

### OCCLUDED FRONT

As a cold front moves across the country, sometimes it can overtake a leading warm front. If the two frontal types combine, they can form an occluded front. In this case, the steep-faced cold front overrides the shallow, wedge-shaped warm front. Cold air hugs the ground surface, forcing the wedge of warm air aloft. A result is that, at the surface, only two cold air masses are felt and temperature remains about the same.

These mixed fronts produce weak results of both cold and warm fronts. As the front approaches, conditions resemble a warm front with the slow building of clouds and rain. The weather can abruptly intensify as the steep cold front part of the front approaches before the rain ends. Occluded fronts tend to move very slowly, and inclement conditions can persist for several days.

**furan** There are many varieties of furan, ranging from the pure form to many varieties of benzofuran and dibenzofuran, which forms a compound class similar to dibenzodioxin, better known as dioxin. Furans are also known as divinyl oxide, tetrole, furan, oxole, 1,4-epoxy-1,3-butadiene, axole, and oxacyclopentadiene. The chlorodibenzofurans, or CDFs, are of special interest because of their pronounced adverse health effects and similarity to dioxins. There are 135 different types, or congeners, of CDFs, which vary in the number and position of chlorine atoms in the structure. Unlike several of the other furans, CDFs have no beneficial use and are simply undesirable by-products of industrial processes. CDFs have been identified in 51 of the first 1,416 U. S. Environmental Protection Agency (EPA)–designated Superfund sites on the National Priorities List. The 2007 CERCLA list of the top 275 most dangerous chemicals includes several CDFs, including octoCDF at number 162, heptaCDF at number 166, pentaCDF at number 168, hexaCDF at number 181, general CDF at number 236, as well as dibenzofuran at number 186, among others. Although furans are not regarded as the most dangerous of chemicals,

as indicated by their rank, their widespread nature and similarity to dioxin, with which they commonly occur, make them potentially very harmful to public health and the environment.

### PROPERTIES, USE, AND PRODUCTION

Furan is classified as a heterocyclic organic compound and a cyclic dienic ether. It is both synthetically produced and naturally occurring in pine resin and sorb trees. In pure form, it is a clear, colorless liquid with an etherlike odor that is flammable and evaporates readily. CDFs, on the other hand, tend to be white solids where they have been able to be isolated. Furan has been mainly used as a chemical intermediate in the synthesis of other industrial chemicals. It is also used in the production of lacquers, as a solvent for resins, and in production of agricultural insecticides, chemical stabilizers, and pharmaceuticals. There is very little information on the production of furan; the United States imported some 9.7 million pounds (4.4 million kg) in 1986. CDFs have no commercial value and as such are only produced in small quantities for research purposes, if at all.

### ENVIRONMENTAL RELEASE AND FATE

Furans are released to the environment in a number of ways. They may be released as point source pollutants from manufacturing, transport, and storage facilities as spills or through improper disposal. They also may be released from point sources as a by-product of oil refining, coal mining, and coal gasification. They are also released in cigarette smoke, wood smoke, and automobile exhaust as a nonpoint source pollutant. Furan is also produced from the distillation of wood. Accidental fires or breakdowns of transformers and electrical equipment that contain polychlorinated biphenyls (PCBs) may produce CDFs. They are also by-products of the manufacture of certain chlorinated chemicals, wood treatment chemicals, some metals, and some paper products. Sludge from wastewater, emissions from municipal and industrial incinerators, and the burning of coal, wood, and home heating oil also contain CDFs as point source and nonpoint source pollution.

When released into the air, CDFs are primarily solid particles but also vapor. Depending upon the CDF, they may remain in the atmosphere and be transported long distances before settling to the ground through precipitation. Some of the airborne CDF is degraded by reaction with photochemically produced hydroxyl radicals. The average duration of CDF in the atmosphere is 10 days or more and lasting up to several months under certain conditions.

If released into the soil, CDFs tend to bind strongly to many types of soil particles and remain fixed, in some cases, for several years depending upon conditions. In some situations, CDFs may leach into the groundwater system, especially in waste sites where concentrations are high. It is more common that CDFs are removed from soils to surface waters by erosion. In surface water, CDFs tend to bind to suspended particles and settle into the sediment, where they may remain for years. CDFs are strongly bioaccumulated by fish and other aquatic organisms to levels tens of thousands times higher than the ambient water levels. When animals or humans eat the tainted fish, they may require a significant dose of CDFs. Studies have also found CDFs in milk and beef. Plants do not uptake CDFs significantly, but they can contain it from atmospheric settling on their leaves and other surfaces. When cattle or other animals eat the affected plants, they can accumulate CDFs. There are no specific studies found on other furans, but because CDFs behave similarly to dioxins, they are expected to follow the same pattern of environmental fate.

### HEALTH EFFECTS FROM EXPOSURE

Exposure to furans of any type can yield severe adverse health effects. Acute exposure typically causes irritation to chemical burns of the skin and eyes through contact. Inhalation can irritate the nose, throat, and lungs, and pulmonary edema is common at higher dosage. The central nervous system is also commonly affected, with headache, dizziness, lightheadedness, unconsciousness, and coma at higher dosage. Very high doses can be fatal. Long-term exposure has been shown to produce weight loss and damage to the thymus, reproductive organs, liver, and kidney, as well as increased mortality rates in laboratory animals.

Acute exposure to CDFs yields similar effects to furan exposure, in addition to chloracne, darkened skin color, swollen eyelids with discharge from the eyes, vomiting, and diarrhea. Longer-term exposure produced anemia, lung infections, numbness, and damage to the central nervous system and liver, in addition to the symptoms of furan exposure. CDFs also caused birth defects, skin problems, and learning and developmental problems in offspring of exposed mothers.

The International Agency for Research on Cancer (IARC) considers furan to be reasonably anticipated to be a human carcinogen on the basis of the results of laboratory testing on animals. It has been shown to increase the incidence of cancer of the liver, adrenal glands, and forestomach, as well as leukemia. Laboratory testing further showed it to be mutagenic to mammal cells, producing chromosomal aberrations and sister chromatid exchanges.

### REGULATIONS ON HUMAN EXPOSURE

Surprisingly, considering the widespread nature and health effects, there are very few federal regulations limiting exposure to furans of all types. The EPA requires that all industrial releases and spills of furan in quantities of 100 pounds (45.5 kg) or more must be reported to the National Response Center. They also consider CDFs to be hazardous waste products.

See also DIOXIN; ORGANIC POLLUTANTS; PCBs; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SOIL POLLUTION; SUPERFUND SITES; WATER POLLUTION.

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# G

**Giardia** *Giardia* is a genus of protozoan parasites that is responsible for most intestinal infections in humans in the world. It is widespread in the environment and able to infect mammals, birds, reptiles, amphibians, as well as humans, and is found in beavers, muskrats, wading birds, voles, mice, shrews, gerbils, rats, deer, native marsupials, and humans in the United States alone. Although there are many species of giardia, those that infect humans are *Giardia lamblia* (most common in the United States), *Giardia duodenalis*, and *Giardia intestinalis*. Since monitoring began in 1971, *Giardia* has been the most abundant pathogen in waterborne human disease outbreaks in the United States. Between 1971 and 2000, more than 130 *Giardia* outbreaks were reported in 27 states. As many as 250 of every 10,000 Americans are infected each year, and, between 1979 and 1988, more than 4,600 were hospitalized annually. The World Health Organization estimates that some 200 million people are infected each year worldwide. The reason that it is so widespread is a function of the life cycle and ability to survive in many environmental conditions.

## SOURCE AND DISTRIBUTION

The life cycle of *Giardia* begins when the trophozoite divides by binary fission and attaches to the brush border of the epithelium in the small intestines. They detach after a period and become rounded cysts through exposure to bile in the upper bowel, while building a resistant cyst wall in the lower small intestines. The cysts are then excreted in feces and move passively through the environment, primarily

in water. The cysts may then be ingested by another animal host, where exposure to low-pH conditions in the stomach allows the cyst to advance to the trophozoite stage, and the cycle begins again.

*Giardia* is found worldwide in lakes, ponds, rivers, and streams, and even in high-quality water sources such as springs. All surface waters on Earth probably contain *Giardia*, but they are more abundant in certain areas. The concentrations range from 38,000 to 380,000 cysts per gallon (10,000–100,000 cysts per liter) in untreated sewage, 38–380 cysts per gallon (10–100 cysts per liter) in treated sewage, and fewer than 38 cysts per gallon (10 cysts per liter) in clean surface water and tap water. Animals in agricultural areas are commonly infected, especially calves, lambs, and dogs, and surface waters in these areas have high concentrations. In the United States, the levels are highest in the late summer through early winter. Cysts cannot withstand hard freezing, but they can persist for periods up to two to three months in cold water at temperatures less than 50°F (10°C). They are all killed at water temperatures in excess of 129°F (54°C) within 10 minutes.

People are more commonly infected with *Giardia* if they use surface water sources that are unfiltered, shallow well water systems, or contaminated water for drinking while camping or hiking. They might also be infected by accidentally ingesting water while swimming or engaging in other water-related recreational activities. Poorly maintained wading and swimming pools and heavily recreated ponds and lakes are especially notorious for *Giardia* transmission. Even springs, which are typically regarded as pristine, were found to be 14–19 percent contaminated in separate studies.

### HEALTH EFFECTS FROM EXPOSURE

The incubation period for *Giardia* ranges from 3 to 25 days after exposure, with the most common at 7–13 days. The infection is commonly asymptomatic in children, and even many adults exhibit no symptoms. A great number of people have probably been infected and do not even know it. The most common symptom is diarrhea. It can vary from transient and mild, passing without notice, to severe and/or chronic. Other symptoms include abdominal cramps, bloating, flatulence, steatorrhea (loss of fat in feces), weight loss, and occasional vomiting. Weight loss may be significant, up to 10–20 percent. In some cases, the infection lasts only three to four days (most commonly), whereas in others, symptoms can last for months or even years. There is also a correlation between *Giardia* and pancreatic insufficiency or hepatic cirrhosis, but it is not clear whether the *Giardia* causes the pancreas and liver problems or whether people who have those problems are more prone to *Giardia* infections. Acquired immunodeficiency syndrome (AIDS) and cystic fibrosis patients tend to have more serious and prolonged infections as well.

Most people who are hospitalized for *Giardia* infections are children younger than age five suffering from dehydration, and the length of stay averages four days. Between 1979 and 1988, 66 percent of the hospitalized cases in Michigan were infants of one year or younger. A potential complication of *Giardia* infections in children is nutritional insufficiency, which can lead to growth and developmental problems. Complications can include poor absorption of iron, allergic reactions, inflammation of the synovial membranes in joints, and reversible retinal problems.

*Giardia* is common in child and infant day-care centers. The infection rate has been found to range from 7 to as high as 54 percent in the United States, and even day-care workers are estimated to have infection rates of 9–35 percent. On a worldwide basis, it is estimated that infection among children commonly ranges from 1 to 36 percent but exceeds 68 percent in some countries.

### REGULATIONS ON HUMAN EXPOSURE

The U.S. Environmental Protection Agency (EPA) has set a Surface Water Treatment Rule (SWTR) that public water systems must filter and disinfect surface water as well as groundwater that is directly impacted by surface water. In this process, at least 99.9 percent of all *Giardia* cysts must be removed or killed.

See also WATER POLLUTION.

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**glacial deposits** There is a general name for all glacial deposits, which is *drift*. If the sediment is carried and deposited by ice, it is called till. If it is carried by meltwater, it is called outwash. Ice can carry any size sediment with the same amount of energy. For this reason, till is very poorly sorted, or, in other words, sediments of all sizes from clay to boulders are typically mixed together. It takes faster-flowing water, however, to carry larger sediments. As water slows, sediments drop out of suspension in size order, larger to smaller. For this reason, sediments deposited by water (outwash deposits) tend to be better sorted, or, in other words, like-sized sediments tend to be deposited together. Outwash is not as well sorted as beach sand, but it is much better sorted than till.

### ICE DEPOSITS

In general, sediments on hillslopes and hilltops (even if plains) are deposited by ice. The general term for most unsorted deposits is *upland till*. There are, however, a few specific deposit types from ice.

### Erratics

Glacial erratics are large boulders commonly sitting perched on bedrock. These boulders can be large





Outwash from glacial streams formed these well-known cliffs at Gay Head on Martha's Vineyard, an island off the coast of Massachusetts. (© Walter Bibikow/Corbis)

as a house and resting on bedrock or perched on small boulders, referred to locally as tripod rocks to reflect their footing. Typically, these erratics will be the only glacial deposits on a scraped bedrock surface. Other erratics appear encased in normal glacial till deposits. These large rocks are more commonly overlooked because their appearance is less dramatic. They simply appear as low swales of rock on the landscape and may be confused for bedrock in some cases.

Glacial ice transports all sizes of material together by encasing them in snow and ice and lifting them off the ground in a mass. As the ice melts, it then releases all of the material in a deposit. Although, in rare cases, a large rock could be dislodged from the ice by subglacial contact with bedrock, it is more commonly dumped with all of the other sediments. For this reason, the erratics encased in till are, by far, the most common. In most cases, the erratics left perched on hills as a single deposit or group of deposits result from the erosion of all of the other till by glacial outwash or later weathering.

### Boulder Fields

In most cases, the glacier did not carry one or a few huge rocks such as those seen in erratics but instead carried a group of boulders in the one-to-six foot (0.3–1.8 m) range. These rocks were carried along and deposited with all of the other sediment sizes. The grinding and scraping of these rocks during transport tended to round their edges. If, sometime after deposition, these mixtures of sediments were subjected to erosion by water, all of the finer material may have been removed, leaving only these rounded boulders behind. The deposit of boulders is called a boulder field and is really an erosional feature.

The formation of a boulder field can be observed in areas where the edge of a till deposit is removed by excavation during a construction project. As the hill face is weathered and eroded, the fine material is removed first, leaving the boulders protruding. At some point, these boulders break loose and roll down to the base of the hill, forming a pile. Although not exactly the same, this is an analogous process to the formation of a boulder field.

### Moraines

A moraine is a much larger feature than an erratic or boulder field, which are small and local. It is a large deposit of till that marks the edge or end of the glacier. Glaciers slowly but continuously move toward areas of higher temperature. At some point, the temperature increase and consequent melting balance the movement speed, marking the end of the glacier. All of the entrained rock and soil is deposited as the ice melts away, leaving a large deposit of till. The duration that this end of the glacier remains in one spot during the conditions of changing temperature determines how extensive the moraine deposit will be. The deposit at the farthest extent of the glacier (to the south or downhill) is the terminal moraine. This is typically the largest moraine because the termination of the glacier remains there longest and can form rather large landmasses such as Long Island, New York. The topography of such moraines can be quite dramatic,



Granite erratic left by retreating glaciers during the Cretaceous period in Enchantment Basin, Washington, near Mount Stuart © Joel W. Rogers/CORBIS

with piles of sediment on the order of hundreds of feet high and miles wide in places.

As the ice retreats during the waning period of an ice age, it does so in stages. It retreats quickly for a distance and then stabilizes for a period. Each time the retreat stalls, a recessional moraine accumulates at the front of the glacier. Recessional moraines are typically much smaller than the terminal moraine and form parallel bands of sediment across the landscape. By definition, these moraines formed parallel to the end of the glacier and perpendicular to the direction of ice flow. Although many glacial features disrupt local surface water drainage, moraine deposits can be the most effective. They create extensive wetlands, ponds, and lakes locally. One reason that drainage is not worse around moraines is that they are generally collocated with outwash deposits, which are generally well drained.

### WATER DEPOSITS

Water is released from glaciers both by heating of the surface by the Sun and by the pressure generated by the weight of the glacier on the base. The pressure is highest where the ice has contact with protruding bedrock. Melting tends to take place at these points similarly to the phenomenon of ice melting beneath the blades of ice skates at the small area of contact that supports the weight of the skater. Just as with ice skating, this melting causes the contact to be slippery and promotes movement. Subglacial meltwater is generated in this way as well as by infiltration of surface meltwater through cracks to the base of the glacier. Some of this infiltrating water may also form and flow through tunnels in the ice at intermediate levels of the glacier. This water may or may not carry sediment. All levels of water exit the glacier and combine at its termination, yielding vast quantities of freshwater. All of these flows produce different glacial deposits.

### Eskers

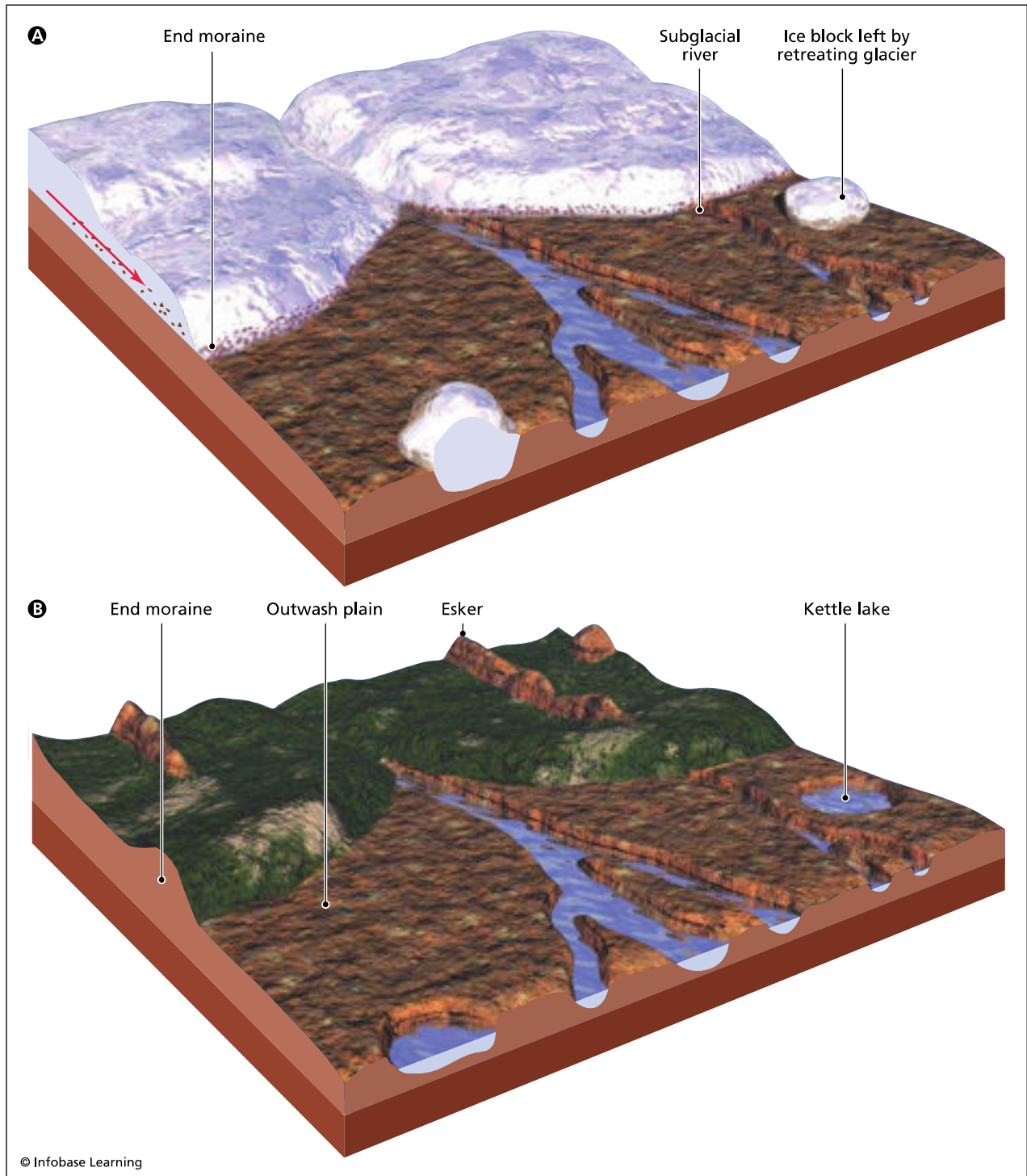
Tunnels form at the base of the glacier within which the subglacial meltwater escapes. Subglacial meltwater washes over the ground surface during its journey and picks up significant amounts of sediment. As the water slows within the tunnel during periods of reduced flow, it deposits the sediments within the tunnel. After the glacier retreats, many of these tunnel fills are preserved as eskers. They appear as long, very narrow ridges up to 30 feet (9.2 m) high and miles long. They look like strands of spaghetti on a map. The sediments within the eskers are relatively



well sorted because they are deposited by water and are generally coarse grained. They are characterized by high porosity and permeability, and as a result, may transmit water and gas freely.

### Glacial Lakes

With all of the meltwater generated at the end of the glacier and disrupted drainage from the moraines, significant glacial lakes may develop. These lakes



**Block diagram (A)** shows the processes at the end of a glacier including generation of meltwater and the entrainment and accumulation of rock, soil, and debris at the melting edge. **Block diagram (B)** shows the results of those processes including an end moraine, an esker filling the former subglacial river tunnel, and an outwash plain from the rivers.

may be tens of miles across and hundreds of feet deep. Because these lakes form in ice ages, they are frozen most of the year. The ice cover eliminates surface input and waves that might stir up the sediment. Sedimentation during this time is restricted to very fine-grained material (clays) at a very slow rate. In the summer months, the ice melts, and slightly coarser material may be deposited both from increased input from higher volumes of meltwater and from increased churning from surface waves. The result is a deposit of very finely interlayered clay and silt, called varves. Each layer is about 0.1 inch (0.25 cm) or less and represents a season. These deposits have extremely low porosity and permeability and are good for containing dangerous materials. In some cases, the lakes may contain significant vegetation, especially in swampy areas, and the deposits may be organic-rich and black in color. These deposits are prized for agricultural purposes.

As the glacier melts at the end, chunks of ice may calve off into the glacial lake and form rafts. These rafts can float all the way across the lake before melting. As they melt, they release any sediment they might be carrying. Large pieces of sediment, such as cobbles and boulders, drop through the water and embed themselves into the varve deposits, typically deforming and disrupting the fine layering beneath. These deposits are called dropstones and are one of the main determining factors in distinguishing a glacial lake from any other lake in a temperate to cold climate.

In many cases, the glacier itself actually forms part of the dam that retains the water in a glacial lake. When the glacier retreats during a warming period, the dam may be broken. The removal of the ice that dams the lake from below the lake bed to the water surface allows the entire lake to drain at once. This draining may produce catastrophic flooding, the likes of which are rare in the history of the Earth. The floodwaters may scour huge canyons and remove huge amounts of sediment in a matter of days. Such catastrophic events have been interpreted for the channeled scablands in western Washington. The massive Glacial Lake Missoula stretched across Washington, Idaho, and Montana. It was 2,000 feet (610 m) deep and 200 miles across (322 km) and contained more than 500 cubic miles (2 billion cubic decameters) of water, or more water than Lake Erie and Lake Ontario combined. It essentially formed an inland sea during the ice ages. When the largest of the ice dams failed, water burst through at a rate 10 times the combined flow of all the current rivers of the world. This flood is documented to have stripped away hundreds of feet of soil and cut deep canyons—coulees—into the underlying bedrock.

This is how the Grand Coulee formed. With flood speeds approaching 65 miles (105 km) per hour, the entire lake drained westward into the Pacific Ocean in about 48 hours. The floods carved out 50 cubic miles (208 million cubic decameters) of earth, piled mountains of gravel 30 stories high, created giant ripple marks the height of three-story buildings, and scattered 200-ton (181-metric-ton) boulders from the Rockies to the Willamette Valley.

### Kame Deposits

Instead of single or dispersed rocks, some of the calved icebergs carried large pockets of sediment. The pockets typically formed as potholes in the ice or part of the intermediate-level tunnels in the glacier. They filled with sediment carried and deposited by meltwater as it lost velocity. In other cases, the sediment may have been moraine material that deposited on glacial ice. In either case, the iceberg rafted the sediment out into the middle of the lake and then melted. The sediment fell to the bottom of the lake in a jumble and deposited on the varved clays of the lake deposits, typically deforming and disrupting them. It is common for these relatively porous and permeable deposits to form perched aquifers.

### Kame Deltas

As meltwater flows from the glacier into the glacial lake, it loses velocity and can no longer carry sediment. As a result, all of the sediment drops out of suspension at the mouth of the stream in the glacial lake, forming a delta. These deltas form similarly to constructive deltas in the ocean. The receiving lake has such small waves that most of the deposited sediment remains at the mouth of the meltwater stream, creating a sizable area of land. The delta has many of the same features as an ocean delta including channels, levees, and channel splays. There are, however, some major differences. Whereas sea level is very slow to change, allowing deltas to remain at a stable elevation for a long period, glacial lakes experience radical level changes from bursting of ice dams—in the lake (lowering), in small lakes above the main lake (raising), or in glacial surge or calving of icebergs into the lake (raising), among others. The radical and significant lake level changes cause the delta to reestablish at various levels, forming terraced delta deposits.

The main glacial lake commonly forms at the foot of the glacier. The position of the termination of the glacier is determined by the interplay of ambient temperature and glacial surge (southward movement). If the temperature decreases or the movement increases, the glacier surges southward and may overrun the lake. The mass of ice deforms the glacial deposits as



well as the lake deposits along the margin, folding, faulting, and contorting the layers. These ice deformation features are common. The constant freezing and thawing of the lake also affect sedimentation patterns. Freezing slows and can stop flow of meltwater, allowing the deposition of clays and other fine-grained materials on the otherwise coarse sands and gravels, forming very distinctive layering.

### Drumlins

It is still debatable as to whether drumlins are deposited by ice or water, but it is likely that their formation is through a combination of the two. Drumlins are elongate features composed of till that are up to one mile (1.6 km) in length, one half-mile (800 m) in width, and more than 160 feet (50 m) in height. The north end of the drumlin (facing the glacier) is steep and elevated, whereas the south end (flow direction) tapers down to ground level. Drumlins are commonly grouped together in swarms in which they overlap each other. Areas with swarms of drumlins are referred to as having “basket of eggs” topography because of their form, though they look more like fish scales. Internally, the deposit is composed of till, but some of the sediment shows evidence of flow, including layering of pebbles and cobbles inclined in the direction of flow (imbrication) and internal sorting locally.

There is some debate about how drumlins are formed; the most widely accepted current idea is that

they were formed when the ice became overloaded with sediment. When the competence of the glacier was reduced, material was deposited. The deposited sediment then appears to have been modified by heavy subglacial flow of meltwater, shaping it into the characteristic drumlin shape. Studies of regional distribution and shapes show that they formed best where the meltwater flowed quickly downhill with ample headroom and deteriorated where the meltwater was forced uphill.

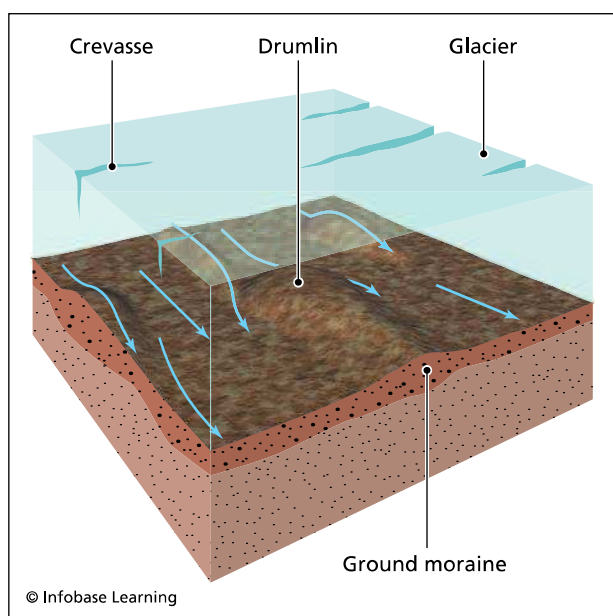
### Roches Moutonnées

Roughly translated as “woolly rock,” roches moutonnées are erosional features formed by scraping of the glacier on underlying bedrock. They look similar to drumlins with a steep side (typically vertical) similar to the hindquarters of a sheep and a sloping, tapered side similar to a sheep head in grazing position. Unlike the drumlin, the roches moutonnées are made of exposed bedrock, and the steep and shallow sides are reversed with the shallow side toward the glacier and steep side away. The shallow side is simply formed from abrasion of the rock surface by materials carried in the flowing ice; the steep side is formed from plucking of pieces of bedrock by the glacier, primarily by breaking along steep joints, thus the steep angle.

## GLACIAL DEPOSITS AND POLLUTION

With so many different types of glacial deposits, no single summary of their properties relative to pollution is possible. Outwash deposits tend to be stratified and well sorted, producing good porosity and permeability. They commonly form shallow aquifers but only in valleys and lowlands, where they can be 100 feet (30 m) thick or more in many areas. Outwash deposits are sparse and thin on hillslopes. The sediments are unconsolidated in these deposits and transmit water well, yielding natural springs in many areas. The high permeability also has its drawbacks, as groundwater is not purified as readily in outwash deposits as it is in other units, and it can be quickly overwhelmed with pollution from overindustrialization or housing development. In this case, the water quality may be compromised.

Glacial till is commonly too thin and so poorly sorted that it does not make a good aquifer. The mix of grain sizes limits the porosity and permeability, making it a poor aquifer. On the other hand, its components of ground-up rock and soil tend to be chemically reactive, and the high clay content filters water well. For this reason, it is generally better at purifying groundwater than the same vol-



**Block diagram showing the formation of drumlins beneath a glacier, with the blue arrows representing subglacial water flow**

ume of outwash deposits. Till can contain mixed-in trees and other vegetation that can rot and produce methane gas that is trapped with the groundwater. There have been cases when this methane has entered homes through the water supply (pipes) and accumulated in indoor air. Methane displaces oxygen in the home and can be toxic to humans and animals, causing suffocation. In water wells that were hand dug, released methane in the well has been known to be fatal. Methane is also highly flammable and has been reported to have blown up homes in Minnesota and other areas when inadvertently ignited. Other glacial deposits, especially related to swamps and lakes, have also been known to produce methane.

Clay deposits, especially in glacial lakes, have a very low porosity and permeability. They are excellent at containing hazardous materials and keeping them sequestered from the groundwater system. This was the case in Love Canal, New York, where the highly toxic substances in the chemical dump would probably have been relatively safe if homes and a school had not been built on top of it and broken through the protective clay cap. It is important that, if such substances are stored in glacial clay, there are no leaks and that the clay is not disturbed. Kame deposits may form perched water tables in glacial clays and must be accounted for before they can be used for waste storage or disposal.

*See also* AQUIFER; GLACIATION; LOVE CANAL.

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**glaciation** The accumulation of ice and snow on a continuous and long-term basis is glaciation. The precipitation generally falls as snow and is compacted to firn and neve before becoming glacial ice, though melting can enhance the process. There are two types of glaciation, continental and alpine. Both types involve the movement of thick

ice bodies, continuous renewal, and melting. Both types entrain rock, soil, and other debris and form distinctive deposits. Alpine, however, is restricted to the mountains and is typically young, whereas continental is located on relatively flat land in polar regions. It only extends away from those areas during ice ages.

#### ALPINE GLACIERS

Glaciers form in mountains as a function of global climate, elevation, and latitude. As long as a mountain is in an area that receives precipitation (snow) and some part of it remains below freezing for enough of the year to support permanent ice, alpine glaciation will occur. If a mountain is high enough and/or the global climate is cool enough, alpine glaciers can even occur at the equator; such glaciers are not common. Most high mountains have some glaciation. As soon as ice is thick enough, under the force of gravity, it begins to flow downhill very slowly in the zone of transport. As it moves, the ice moves to warmer temperatures at lower elevation, and it melts. In the zone of ablation ice is removed from the glacier by melting. At a certain point, melting back will equal the downward surge of the ice. That point is the end, or termination, of the glacier. The point shifts downhill in winter and uphill in summer and shifts on a longer-term basis with global cooling or warming.

Alpine glaciers are erosional agents at the tops of mountains and depositional agents at the base. Glacial ice forms in an area of accumulation, and, as it moves, it scrapes out the rock and soil beneath it. The scoop-shaped indentation it leaves behind is called a cirque. As the ice scoops out many cirques, they reshape the peak of the mountain as they coalesce into an arête and finally a horn. All of the ice flows that form the cirques flow together as in tributaries of a river to make a larger alpine glacier. Unlike in a river, as they combine, they do not mix but simply add width to the edges of the glacier. Each added glacier from a tributary can even be distinguished within the main glacier. The reason for this is that the edges of the glaciers entrain rock and soil called a marginal moraine. As the glaciers combine, they retain their moraines, and the moraines enter the main glacier as medial moraines. The medial moraines appear as dark stripes on the otherwise white glacial ice, parallel to the flow direction and permanently marking the added tributary glaciers in the main glacier. The glacier bends as it winds its way down the mountain and forms numerous cracks in this process called crevasses.



**Mendenhall Glacier in Alaska** (*Joy M. Prescott; used under license from Shutterstock, Inc.*)

Unlike rivers that form V-shaped valleys through erosion, when glaciers flow down a mountain, they form U-shaped valleys. This is because the weight is spread out over the stiff base. The larger the glacier, the deeper the U-shaped valley. Where the tributary glaciers join the main glacier, they cut much more shallowly into the mountain. Later, when all the ice is melted, these tributary valleys will form shallow hanging valleys on the deep valley wall of the main glacier.

Both the weight of the ice pressing the base on the valley floor and the heat of the Sun will cause the ice to melt. All of this melting means that the termination of the glacier typically has much meltwater flowing out of it. There are typically rivers emanating from the ends of alpine glaciers. In addition, both the ice and meltwater carry a lot of sediment, much of which is dumped at the end of the glacier in a moraine. The piles of sediment may dam up this river and form a pond and/or swamp at the end of the glacier, as well. The exact nature of the sediments and surface waters at the end of the glacier depends upon whether the end of the glacier is in the mountains, at the base of the mountains, in the ocean, or in a large lake.

### CONTINENTAL GLACIATION

Continental glaciers are present today primarily on Antarctica and Greenland. During ice ages, however, they can extend all the way to the midlatitudes. These glaciers operate similarly to alpine glaciers with zones of accumulation, transport, and ablation. Continental glaciers, however, are much larger, forming huge sheets the size of continents. Snow accumulates up to one mile (1.6 km) thick, and the entire mass moves away from the Poles at slow speed.

In the last ice age, continental glaciers extended southward to New York City and across the northern border of the United States. The water to make all of this ice was from the oceans. Sea level dropped some 200 feet (61 m), exposing the continental shelves as land. Previously slow rivers became raging torrents, cutting deep canyons all the way out onto the exposed shelves. The moving glaciers entrained huge amounts of rock and soil and continuously deposited them at the melting southern end of the glacier. Long Island, New York, was formed by this process, as were Cape Cod and Martha's Vineyard and related islands in Massachusetts. As the glaciers melted at their base from overburden pressure and at their tops from sunlight, they formed large subglacial rivers



feeding into huge lakes. Many of the larger lakes drained after the ice age waned, but the Great Lakes and Finger Lakes of New York were formed by these processes. The weight of the ice sheet depressed the crust of the Earth into the mantle during the ice age, actually lowering the surface elevation.

Most of the features we see today along the coasts and the northern part of the United States are the result of the last ice age. There is a sharp demarcation across the northern part of New Jersey, to the north of which there are numerous lakes and to the south of which there are few, if any. This line can be traced across the United States where states to the north such as Minnesota, which boasts 10,000 lakes, have poor drainage from glacial deposits and states to the south may have no lakes. All rivers widen at the coast, have deep bases, and are estuaries with tides pushing ocean water far up their course. The Hudson River of New York is classified as a fjord; it has a bed more than 200 feet (61 m) below sea level in several areas, in which brackish water has been found as far north as Troy, New York, more than 100 miles (160 km) upstream.

The rising sea level from the melting glaciers, once again, flooded the continental shelves. Trawlers off Long Island sometimes recover mammoth bones. As the seas rose, the ends of the rivers were submerged and the old valleys now form submarine canyons along the coast. The sea level rose faster than the coastal beaches could retreat landward. In most cases, sea level overtook the beach and flooded behind it, creating the system of barrier islands separated from the mainland by lagoons or bays that now characterizes the East Coast and Gulf Coast of the United States. The land level is slowly rising, or rebounding, since the weight of the glacier was removed. Structures that were built on the coast several hundred years ago are now well inland. Perhaps the most impressive example of rebound is in Lake Champlain, New York. When the glacier retreated, the land was so depressed that ocean water connected through the Saint Lawrence Seaway and into the lake. As the surface of the land emerged, Lake Champlain was cut off from the ocean, but whale bones and other evidence of marine life can still be found preserved in the sediments of the now-freshwater lake.

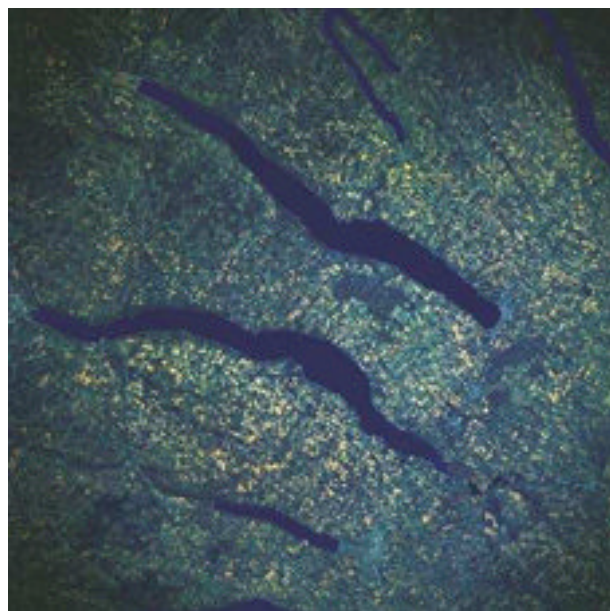
### POLLUTION AND GLACIERS

Glaciers have nothing to do with polluting the Earth. They are, however, excellent recorders of global anthropogenic influence, at least in the polar regions. Snow falls on the continental glaciers every year and is preserved as glacial ice. As the snow is created and falls through the atmosphere, it samples

the chemical makeup. There is much information on climate variations and atmospheric chemistry stored in the ice, and there is now a record for hundreds of thousands of years. Scientific teams drill holes in the ice and retrieve continuous cores that are studied in the laboratory.

One use of ice core study is to see whether anthropogenic chemicals are present. If pesticides or industrial chemicals that do not occur naturally appear in glacial ice, they indicate that they are so abundant in the atmosphere and so long-lived that they occur in all air on a global scale. These data were used to help eliminate the use of some of the more persistent pesticides. Chemical pollutants that are both naturally occurring and synthesized occur throughout the cores. By comparing concentrations of a pollutant in ice prior to the industrial age with that in current glacial snow, the relative influence of humans on accumulation of the pollutant may be evaluated. For example, Pat Patterson compared the abundance of lead in glacial ice from preindustrial times with that in glacial snow from the 1960s to show that concentrations in polar regions were 100 times greater than natural levels. Considering how dense lead is and consequently how quickly it settles out from air, levels near the sources in cities and industrial areas had to be much greater than that.

In addition to pollutants, snow preserves a small sample of air and water as well. Concentrations of carbon dioxide and other naturally occurring gases may be evaluated at various times to chart their variations in polar air. Oxygen and other stable (nonradioactive)



New York State Finger Lakes photographed from space shuttle Challenger, 1985 (© Corbis)





**North Polar view of Earth showing the extent of the continental glacial sheet during an ice age. The small arrows show the local direction of ice movement largely southward or off higher areas and into the oceans.**

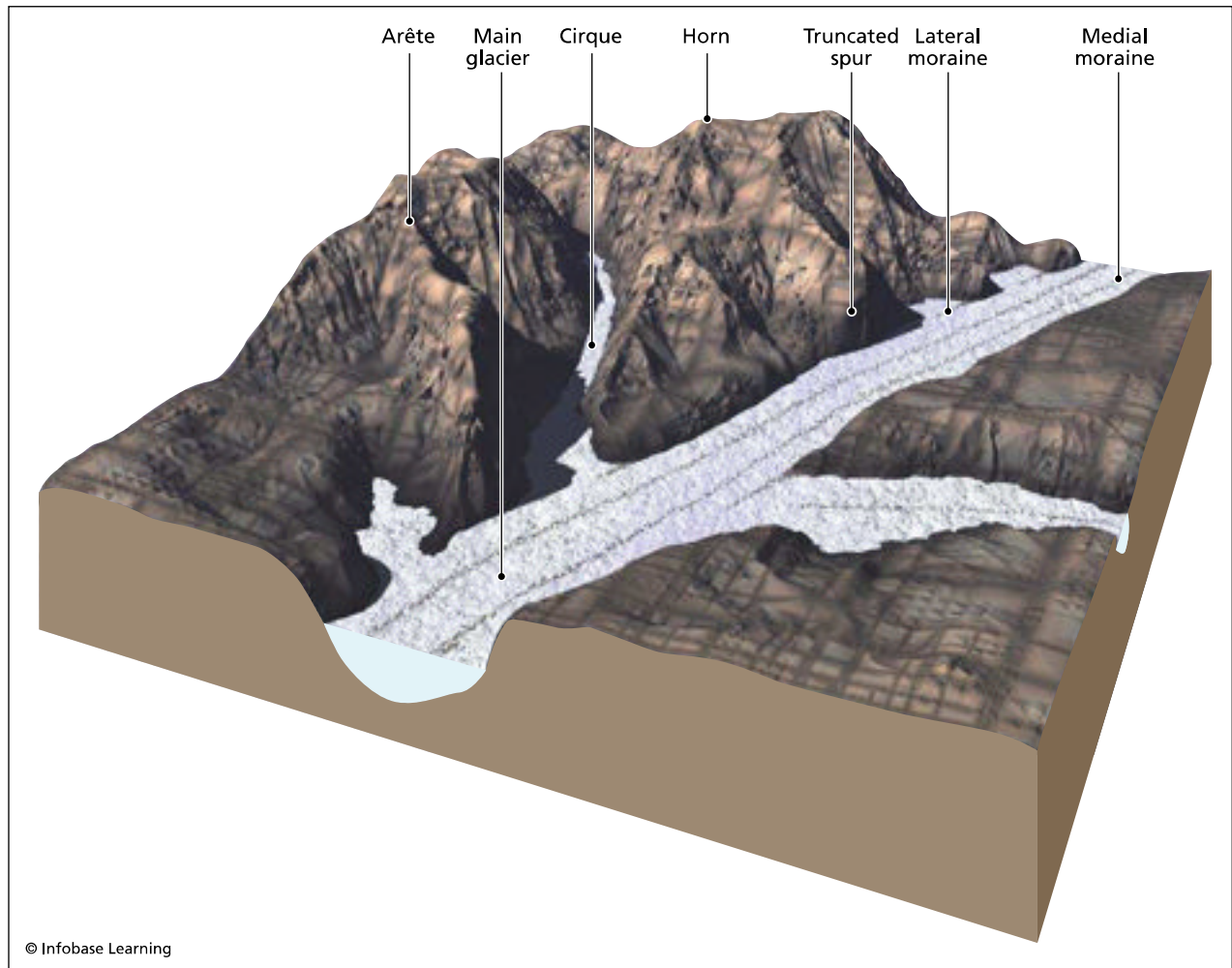
elemental isotopes can also effectively serve as thermometers for the whole Earth. When water is tied up in ice, less is available to ocean water, and the ratio of oxygen isotopes changes as a result. Carbon isotopes may also reflect the amount of biomass present on the planet. Studies of these stable isotopes have been used to evaluate the content of greenhouse gases in the atmosphere and to show the natural variations in the atmosphere. These data can be compared with current conditions to evaluate anthropogenic influence on

atmospheric chemistry and global warming. Ice core data are among the strongest evidence that humans are increasing greenhouse gases and causing global warming.

*See also* CARBON DIOXIDE; GLACIAL DEPOSITS.

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**Block diagram of the features of alpine glaciation. Tributary glaciers carve cirques into mountains and coalesce into main glaciers, each separated by a moraine.**

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**global warming** At the time of the Industrial Revolution (around 1800), the amount of carbon dioxide (CO<sub>2</sub>) in the Earth's atmosphere was about 280 parts per million (ppm). In 2010, atmospheric CO<sub>2</sub> levels were 390 ppm and rising at a rate of 2 ppm per year. Because CO<sub>2</sub> is very effective at capturing

the infrared radiation given off by the Earth's surface after it has been heated by the Sun, the more CO<sub>2</sub> in the atmosphere, the warmer the planet becomes. This process, called global warming, can lead to climate change with major changes in long-term planetary temperatures, precipitation (rainfall) patterns, and even ocean levels. When first observed by atmospheric scientists in the 1950s, the increase in CO<sub>2</sub> levels was thought to be part of the natural variation in the Earth's atmospheric composition that had been taking place for many millions of years. However, the steep increase in CO<sub>2</sub> concentrations (almost 40 percent in 200 years) was much higher than any previously thought to have occurred and appeared to be directly linked to the massive, worldwide burning of fossil fuels that took place during this period. The eight warmest years on record (since 1850) have all occurred since 1998, with the warmest year (so far) 2005. Today, there are few mainstream scientists who



believe the rapidly increasing CO<sub>2</sub> levels in the atmosphere are not anthropogenic (caused by people's activities). However, there is still much uncertainty as to what the impact of a 485-ppm CO<sub>2</sub> atmosphere (anticipated by 2050) will be on human civilization.

Global warming has become the environmental issue that will drive human economic and cultural development for at least the next century. Addressing the issues surrounding this potentially devastating and catastrophic phenomenon has become so popular that the former U.S. vice president Al Gore was awarded the Nobel Prize in 2007 for helping to popularize and draw attention to the problem. He also won an Academy Award the year before for his documentary *An Inconvenient Truth*, an acclaimed and commercially popular documentary that called worldwide attention to ways pending climate change may impact both the United States and other countries around the world. There was even an international rock concert tour in 2007 to highlight threats to human health and the environment from global warming.

There are a small number of politicians and even a smaller number of scientists who vehemently deny global warming is occurring or claim that it is not anthropogenic. They rely on the insignificant scale (smallness) of human activity relative to the size and resiliency of the Earth and are resistant to accepting any connection between the use of fossil fuels and climate change. They see no reason or need to alter the cultural lifestyle of the United States or the rest of the world. As adamant as the global warming proponents, they claim that the climate of the Earth changes all of the time and has since the Earth was formed. However, this view is becoming more and more difficult to sustain in light of the increasing scientific evidence confirming that CO<sub>2</sub>-driven global warming/climate change is occurring. The United Nations, European Union, United States Environmental Protection Agency, National Academies of Sciences, as well as almost every major scientific and research organization in the world have published position statements that confirm CO<sub>2</sub> in the atmosphere is increasing because of fossil fuel usage and



Low-lying areas such as Funafuti Island—capital city of the South Pacific nation of Tuvalu—are particularly susceptible to damage from rising sea levels. (Ashley Cooper/Alamy)

### COMPARISON OF EARLY EARTH AND TODAY'S EARTH ATMOSPHERES

Early Earth Atmosphere (between 4 billion and 2.5 billion years ago)	Today's Atmosphere
H <sub>2</sub> O or water vapor: 80–85 percent	N <sub>2</sub> or nitrogen gas: 78.1 percent
CO <sub>2</sub> or carbon dioxide: 10–15 percent	O <sub>2</sub> or oxygen: 21 percent
CO or carbon monoxide	Ar or argon: 0.9 percent
N <sub>2</sub> or nitrogen gas	CO <sub>2</sub> or carbon dioxide: 0.04 percent
H or hydrogen gas	Other gases: less than 1 percent

that those increases are resulting, or will result, in changes to the Earth's climate.

#### CLIMATE HISTORY OF THE EARTH

Before the current period of global warming can be examined in context, normal climate variations must be defined. The climate of the Earth has varied greatly throughout its history. When the Earth was formed some 4.6 billion years ago, it had no atmosphere as known today. There are indications that there may have been light elements in an atmosphere, but they are speculated to have been removed by the solar wind. The surface of the Earth was so hot from the collisions of asteroids and meteorites that parts of the surface may have been molten rock. The great heat resulted in numerous volcanoes that released gases from the Earth's interior in a process called degassing. Gases that were released from molten rock and debris combined to form the early atmosphere. As the gases cooled and condensed, they rained down liquids that accumulated to form the early oceans.

The early atmosphere was still very warm and chemically very different from the current atmosphere. There was no free oxygen. Rocks of this age have minerals that would have been oxidized at the surface under current conditions, but they are not. The early atmosphere was rich in water vapor and carbon dioxide, which are strong greenhouse gases and certainly contributed to the high surface temperature present at this time in the planet's development.

The first major adjustment in the climate dynamics occurred with the development of photosynthetic cyanobacteria. Beginning around 3 billion years ago, in order to store energy, these primitive bacteria drove a chemical reaction to produce simple sugars as follows:



Although the main point of the process was to store energy in the sugars, the by-product of oxygen in the process had far greater implications for the atmosphere. These implications, however, were a long time in coming, because the free oxygen quickly reacted with one or more of the oxygen-poor compounds in the atmosphere and was removed.

The cyanobacteria, known as stromatolites, colonized the shallow oceans at the shorelines and proliferated about 2.5–3.0 billion years ago. They were so efficient at converting CO<sub>2</sub> into oxygen that by 2.2 billion years ago materials on the surface of the Earth began to oxidize (rust), and “red bed” sequences of rocks began to form. The reduction of CO<sub>2</sub> and other greenhouse gases in the atmosphere cooled the climate, and the first glacial deposits were formed. Since then, the climate has varied. It has mostly been warmer than it is now, but there have been relatively short-duration glacial periods scattered within it. At about 1 billion years ago, the Earth went into an “icehouse” mode, when the entire Earth became cold. Glacial deposits are interpreted to have formed even at very low latitudes. Most of the time after that, the Earth was primarily in a “greenhouse” mode, when there was no ice on the planet at all. Why the Earth shifts back and forth between greenhouse and icehouse modes is not fully understood.

There were major changes in the Earth's atmosphere over the past 500 million years. For example, the largest shift was about 250 million years ago, when plants colonized the land. For many millions of years, there were insufficient numbers of animals or efficiency of the animals to consume the vast amount of vegetation that was being produced. As a result, huge swamps developed, and most of the world's coal supply was produced at this time. Huge amounts of carbon were sequestered in the Earth, and the oxygen supply increased in the atmosphere. Within 25–50 million years, ice ages began again,



but vegetation was no longer being sequestered, as reptiles and dinosaurs evolved to consume it. The ice ages were similar to those of today in extent and duration, but conditions returned to warm and ice-free within a few million years.

About 65 million years ago, a large asteroid collided with the Earth. The evidence for it are an iridium-rich layer at the applicable time and abundant shocked quartz in sediments on a worldwide basis. A crater, named Chicxulub, which appears to be the point of impact, has been identified in the Gulf of Mexico. This collision is credited with having caused the extinction of the dinosaurs along with at least 75 percent of all land-dwelling species on Earth. Some of the most respected scientists at the time the theory was presented proposed that so much dust was emitted into the atmosphere that the Sun was masked for upward of one year. They proposed that it was equivalent to a nuclear winter. Other scientists hypothesized that this impact caused all of the vegetation on the planet to be consumed in a conflagration and cite carbon and oxygen isotope ratios in sediments of that age to prove their point. The problem with these doomsday scenarios is that many modern-day species such as mammals, birds, and frogs survived the event, and doing so would have been difficult if no food was available. This leaves the nature and extent of the damage from this collision in question.

After this period, the climate cooled dramatically as mammals became the dominant group. Rapid cooling separated long periods of stable climate over the next 30–40 million years. Oxygen ratios increased during this time, reaching their highest levels ever. About 4 million years ago, the climate again cooled into an icehouse mode. Since then, the climate has oscillated back and forth between ice ages and interglacial periods. We are currently considered to be in an interglacial period.

### **CAUSES OF GLOBAL WARMING**

There is a complex interplay of many factors that controls the temperature of the planet. Some of these factors are external, whereas others are internal to the atmosphere. The external factors have more control of the climate by far; internal factors are also important within their limitations. These factors are described as follows:

#### **Solar Radiation**

Although it appears that energy from the Sun is a constant, it is not. Evidence of the variability of the Sun includes sunspot activity and solar storms,

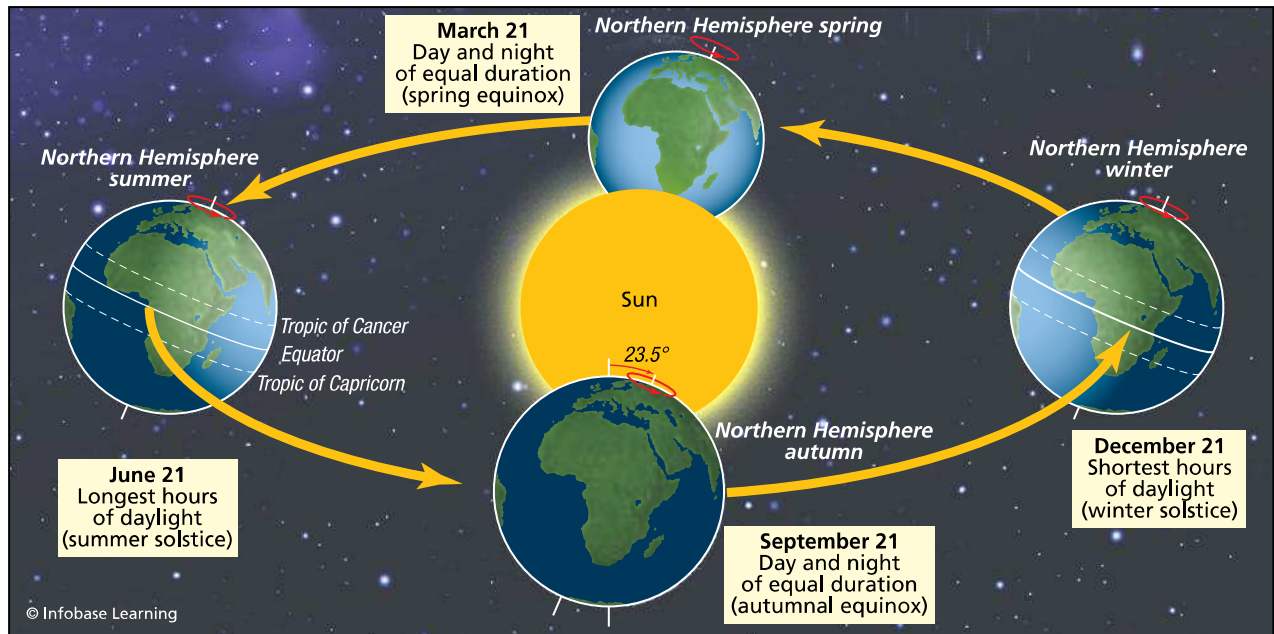
and scientists have even measured solar output for a short time. These variations of solar output show a cyclicity with time, suggesting that they may be part of a larger system of cycles. There even appear to be cycles in the total radiation output of the Sun, as well, though measurements show only small changes. No matter how important the other factors appear in climatology, they are surely dwarfed by the variability of solar output. This factor cannot be completely evaluated with our short period of observational data, but certainly with features like the channels of Mars on an otherwise frozen planet, the possibility of significant changes is not out of the question.

#### **Orbital Changes of the Earth**

The second most important factor in the temperature of the Earth is its distance from the Sun. This is another measure that would appear to be constant, but it changes on even a yearly basis. During the Earth's orbit around the Sun, it has a closest point called the perihelion that occurs on January 3 and a farthest point called the aphelion that occurs on July 4. This is an annual cycle for the orbit. There are other longer-term cycles in the Earth's orbit, as well, with no other outside influence. Scientists have identified a 100,000-year cycle and possibly several others. Add the gravity of other planets that may be closer and farther from the Earth to the equation, and the orbit could vary even more. These changes could be cyclical, as well, or they could be catastrophic.

#### **Tilt of the Earth**

At this point, the rotational axis of the Earth is inclined about 23.5° from the plane of its orbit around the Sun. It is this tilt that gives the Earth seasons. Solar heating of the Earth's surface is strongest when the incident rays of the sun are at 90°. The more gentle the angle of incidence, the less concentrated the radiation will be and the cooler the Earth. That is why the poles are cool and the equator is hot. During the summer solstice on June 21, the Sun rays strike the Earth directly (90°) along the tropic of Cancer at 23.5° north latitude. This is the most northerly point that the Sun rays strike directly during the year. At this point, the Northern Hemisphere is being heated more and is experiencing the warm weather of summer. Six months later, the Earth has moved in its orbit to the opposite side of the Sun and the direct rays strike 23.5° south latitude along the tropic of Capricorn. This is the farthest point south that there is direct radiation. It is the winter solstice and it occurs on December 21. The Southern Hemi-



**Position and tilt of the Earth relative to the Sun for the first day of each season. The yellow arrows show the orbit of the Earth around the Sun, and the red arrows show rotation of the Earth.**

sphere is heated at this time, leaving the Northern Hemisphere to experience the cold weather of winter. During the vernal and autumnal equinoxes on March 23 and September 23, respectively, the direct rays of the Sun strike the equator. That is the hottest place on the planet, as the Northern and Southern Hemispheres have moderating temperatures.

The rotation axis of the Earth, or North Pole, does not remain fixed. It shifts positions in cycles just as the other astronomical variations do. It has a short-term shift in circles that is like a wobbling top in which the Pole remains at 23.5° but points toward different places in the sky in a big circle, shifting from the North Star as the rotation axis. This procession of the axis is a 1,000-year cycle but may have little effect on climate. The Markowitz wobble is a very small angular cycle of shifting position of the pole with a period of about 30 years. Even larger shifts are possible but are probably very slow at about 1° per million years. There is evidence that there were much larger and quicker shifts in the past. If the shift causes the tilt angle to decrease, the effect of seasons will be reduced. The poles will become much colder and glaciers will extend much farther south. If the shift causes the tilt angle to increase, the direct incident rays of the Sun will cover a much larger area throughout the year, and the heat energy will be more evenly distributed. This would tend to reduce the amount of ice at the poles.

### Aerosols in the Atmosphere

Incoming sunlight must be able to reach the ground and be absorbed to heat up the atmosphere. Dust particles and liquid aerosols tend to reflect or disperse the incoming sunlight back into space. The more aerosols and dust particles, the less the Earth will heat. The best example of the power of aerosols in the atmosphere is the Indonesian volcano Tambora. In 1815, Tambora produced a large eruption with about 36 cubic miles (150 km<sup>3</sup>) of ejecta. Much of the ejecta were in the form of fine dust, which was shot high into the atmosphere and spread around the world. This fine dust reflected a portion of the incoming solar radiation back into space, thus reducing the heating of the Earth. As a result, 1816 was referred to as the "year without a summer." Snow fell in New England through the month of June, and, as a result of the cold, there was a worldwide famine. The effect ended within a few years and only 1816 had drastic changes. Tambora, however, was small in comparison to many other volcanoes. The Indonesian volcano Toba, for example, erupted 74,000 years ago and emitted 700 cubic miles (2,800 km<sup>3</sup>) of ejecta. This was well before historical records, so we do not know what effect it had on the weather. There have been many other prehistorical eruptions as large as Toba, which could have drastically altered climate.

Another great potential source of reflecting dust in the atmosphere is an extraterrestrial impact. It

is hypothesized that when the asteroid that potentially caused the extinction of the dinosaurs struck the Earth 65 million years ago, it caused a “nuclear winter.” In this scenario, so much dust is raised into the atmosphere that it reflects back a large percentage of the incoming solar radiation, keeps the whole world in darkness, and drops temperatures to winter conditions throughout the planet. This condition is hypothesized to be intense for one year, and effects could last a decade or more. This is an extreme situation that happens so infrequently that it is typically not factored into any climate models.

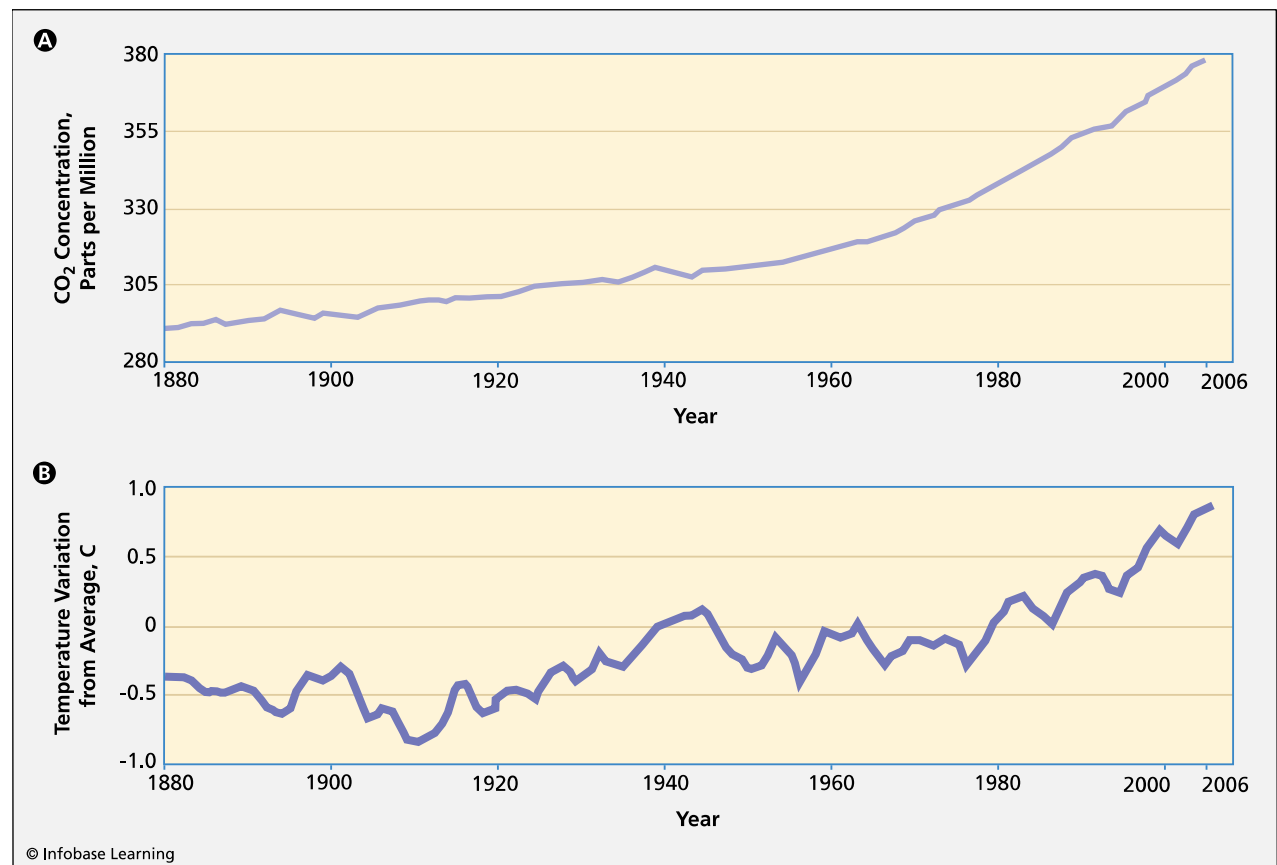
Human activities not only lead to an increase in carbon dioxide in the atmosphere, but also produce an enormous amount of particulate matter. Some scientists are now finding that the rapid melting of glaciers may be the result of particulate covering them and absorbing solar radiation rather than reflecting it, as ice should. Global warming may be a minor effect. This particulate has spread throughout the troposphere and even into the stratosphere. Particulate and aerosols, which have also greatly increased through human activities, reflect the sun-

light back into space. They, therefore, cause global cooling.

The term *nuclear winter* was coined to describe what would happen if there were a nuclear war. Nuclear war would have the capacity to alter the climate greatly. In addition to the many other catastrophic changes to the environment that would ensue from a nuclear war, the explosions would raise enough particulate into the atmosphere that solar radiation would be inhibited at the surface because it would be dispersed and reflected. As a result, it would be dark and very cold on a planetary scale. This scenario is probably moot because there would be few, if any, humans left to witness it.

### Surface Albedo

Several years ago, a major airline conducted a study and found that they could save a significant amount of money in cooling costs by painting the tops of their airplanes white. While waiting to take off, airplanes get very hot sitting on the tarmac. They need to expend fuel needed for flying to run the air-conditioning. Painting the top of the plane white caused



Graphs of changes in carbon dioxide (A) and temperature (B) with time from 1880 to 2000. Measurements of global carbon dioxide from 1880 to 1960 are from trapped gas in ice cores, whereas after 1960 they are measured at Mauna Loa, Hawaii, and show seasonal variations. Temperatures are shown in deviation from average over the recording period and are also from Mauna Loa.

the incoming solar radiation to be reflected away. This is the same reason why white cars are cooler than black cars. The variable that measures reflectivity is called surface albedo. The surface albedo of the Earth varies depending upon the location. In most wooded areas, solar radiation is strongly absorbed, whereas in glacial areas it is reflected. Normally, it is desirable for solar radiation to be absorbed because it can be converted into stored energy by vegetation through photosynthesis. In global warming terms, it is not desirable because more heat is held in the atmosphere. Snow and ice are undesirable because they simply reflect back the energy and do not store it for human or animal consumption. In global warming terms, snow and ice reduce absorption of heat and thereby reduce global warming. This presents a dangerous positive feedback mechanism for global warming. As the temperature climbs, the glacial ice melts and retreats, leaving more surfaces to absorb rather than reflect solar radiation. The newly exposed surface absorbs the solar radiation, thereby heating up the atmosphere and melting more ice and snow.

### Mountain Ranges

The number and distribution of high mountain ranges can also have an effect on climate. High and extensive ranges can divert wind and weather systems to some extent. They can force colder air toward lower latitudes and warmer air toward the Poles. Pulling warm air into colder regions can result in overall warming. Another effect of mountains is to raise the elevation of the surface to where it can support snow cover. The presence of snow cover at lower latitudes reflects back solar radiation that would have been used to heat the planet at normal elevations.

### Ocean Changes

Although it may not be readily apparent, the global climate is strongly influenced by both sea level and ocean circulation. Ocean currents play an integral role in distributing heat around the planet. They moderate coastal and even regional temperatures and precipitation. A good example is the Gulf Stream in the Atlantic Ocean. It keeps the British Isles and most of Western Europe temperate and habitable even though they are at the same latitude as Labrador, Canada, on the other side of the Atlantic Ocean, which is prohibitively cold. In reality, this effect of temperature distribution through ocean circulation is even more profound on the global scale. It is, therefore, essential to have good circulation to keep the temperature moderated. In geologic history, when ocean circulation was reduced, the Poles were much colder and promoted quick global cooling.

This restriction in ocean circulation occurred not only through obstruction by landmasses but also by glacial ice. Not only does the ice freeze the surface of the ocean, it also lowers sea level by the amount of water consumed in producing the glaciers both on land and in the sea. Lower sea level reduces circulation and ocean influence on climate. This is one of the main reasons (in addition to surface albedo and others) that when an ice age begins, it develops very quickly. Scientists describe it as a switch: The ice age is on or it is off; there is no in between.

There are other factors in sea level and ocean circulation as well. These are mainly tectonic in nature. Inflation and deflation of the midocean ridges can cause sea level to vary. During the Paleozoic, from about 500 million years ago to 220 million years ago, the sea level was mainly much higher than it is today because of inflation of the ridges, thus displacing the ocean water. The entire central part of the United States was under a shallow ocean for periods of tens of millions of years at a time. There was much more water in the atmosphere at the time, and circulation of surface waters was greatly enhanced. The ocean basins were shallower as a result of this inflation, and deep circulation was subdued. The Earth was warmer as a result.

### Living Organisms

Although, in most cases, living organisms as populations change too slowly to have an appreciable effect on the atmosphere, radical changes in populations or evolutionary advances can have great effects. Carbon dioxide is removed from the atmosphere and oxygen returned by the photosynthetic activities of plants and bacteria. Any disruption of the plant population by an ice age, asteroid impact, or even global deforestation in productive areas such as rain forests could reduce global photosynthesis and result in excess carbon dioxide. By the same token, any increase in population or evolutionary advances in the photosynthetic capacity of these organisms could increase the amount of oxygen in the atmosphere.

The other organisms that exert control on the composition of the atmosphere are shell-producing organisms in the ocean. The ocean is a huge sink for carbon dioxide as well as other atmospheric gases, and there is a constant exchange. The carbon dioxide in the ocean is used by certain organisms to build shells. The most abundant of these organisms are plankton, algae, and corals. Pollution of the ocean, destruction of habitat, and destruction of reefs by humans have taken their toll on these beneficial organisms. Without them, there would be a surplus of carbon dioxide in the oceans and consequently in the atmosphere as well.

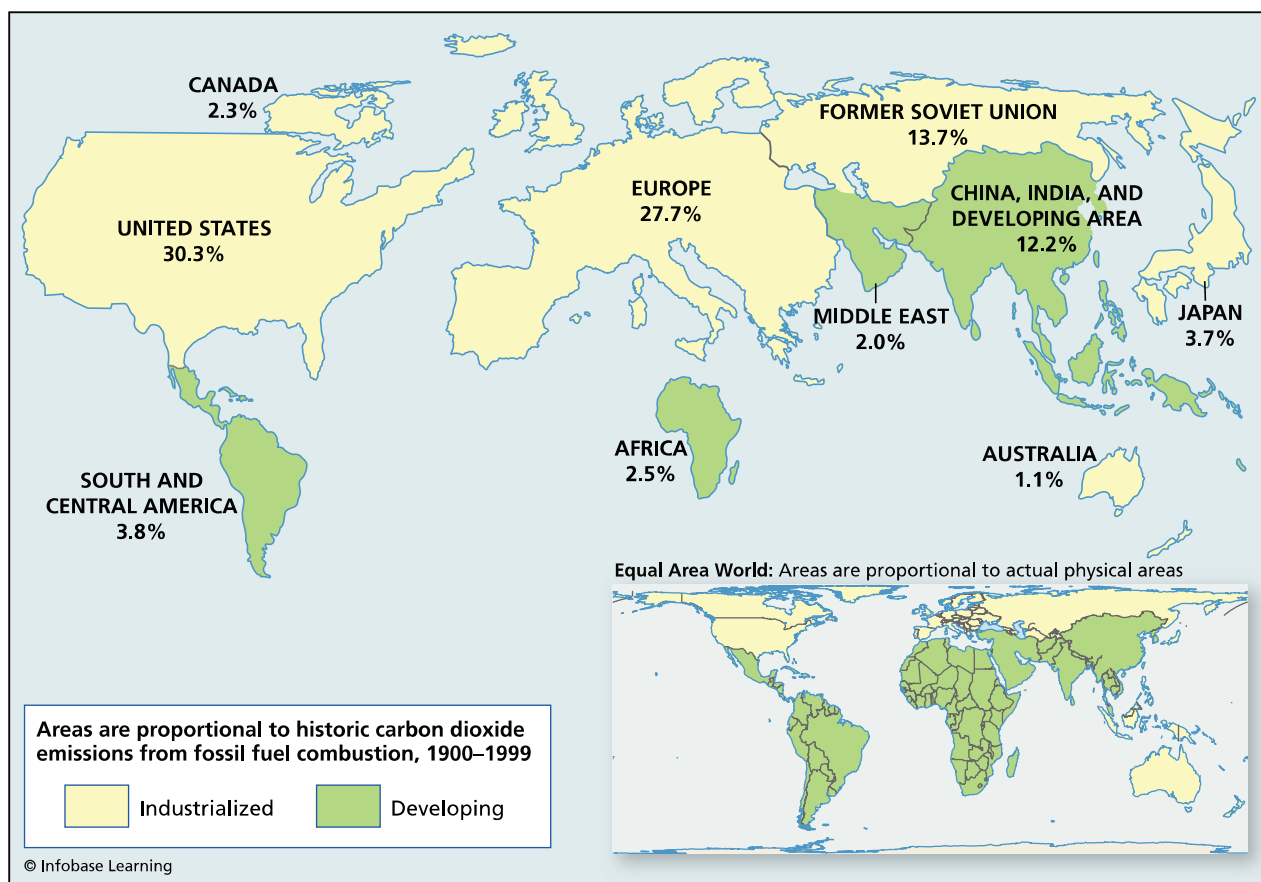


### THE GREENHOUSE EFFECT

The greenhouse effect occurs when solar radiation that enters the atmosphere cannot escape and thus heats it up as in a greenhouse. The reasons that the solar radiation is trapped are several. Incoming solar radiation has a short wavelength and can penetrate all of the gases in the atmosphere. When it is absorbed by the surface, it is converted into long-wavelength radiation or heat. Gases such as oxygen allow the shortwave radiation to pass in and the long-wave radiation to pass back out of the atmosphere again. Certain gases, carbon dioxide, for example, do not allow all of the long-wave radiation to pass back out but instead absorb it. The absorption heats the atmosphere and causes global warming. Carbon dioxide is, therefore, called a greenhouse gas. It is the gas of most concern because it is increasing so fast. In fact, there are much stronger greenhouse gases than carbon dioxide. Methane, for example, which is also increasing dramatically as the result of human activity, is 23 times stronger a greenhouse

gas than carbon dioxide. The amount of anthropogenic methane released to the atmosphere, however, is far less than the amount of carbon dioxide. Other greenhouse gases include nitrogen oxides, chloro-fluorocarbon (CFC) propellants, vapors of numerous organic compounds, and even water vapor.

Anthropogenic carbon dioxide is added to the atmosphere at a rate of an estimated 3.5 million tons (3.2 billion metric tons) annually. Energy-related carbon dioxide emissions, resulting from petroleum and natural gas, represent 82 percent of total U.S. industrial greenhouse gas emissions. This is the reason that all of the focus of the global warming debate has been on carbon dioxide. The question of how we can determine which carbon dioxide is anthropogenic and which is from respiration or other natural sources was answered in the 1950s by Hans Suess. He found that natural carbon dioxide included radiogenic carbon, whereas carbon dioxide from fossil fuels does not. The reason is that radiogenic carbon is produced in the atmosphere



**Schematic map of the world with size of areas (countries or continents) reflecting their average production of carbon dioxide through the 20th century. The numbers on the areas reflect their percentage of the total world production. The inset map shows the areas in their actual sizes.**

and all natural carbon dioxide contains it. Once the carbon is removed from the atmosphere, it decays to a more stable form and the remaining carbon is “dead.” It was the work of Suess and Roger Revelle that led to the recognition of the greenhouse effect. As a result, Revelle has been widely acknowledged as the “grandfather of the greenhouse effect” by most of the current proponents of the theory, including Al Gore. In his book and Academy Award-winning documentary *An Inconvenient Truth*, Gore applauds Revelle for his efforts.

There is no question that carbon dioxide in the atmosphere increased radically in the late 20th century and continues to do so in the 21st century. In his documentary *An Inconvenient Truth*, Al Gore highlights the radical increase from the previous levels and refers to it as the “hockey stick” in the graph. Even though the percentage of carbon dioxide in the atmosphere is still very small, at 0.0384 percent, or 384 parts per million (ppm), this is an increase of 100 ppm from preindustrial times, or an increase of 35 percent. About 20 percent of this 35 percent has occurred since 1960. The questions still in debate are whether this increase in carbon dioxide in the atmosphere is anomalous and whether it is the sole culprit in the current global warming cycle.

### ESTABLISHING A NATURAL VARIATION BASELINE

In order to answer the question of whether these increases in temperature and carbon dioxide levels are really anomalous relative to normal atmospheric variations, scientists must establish what normal is. Federal agencies that fund basic research on the climate and atmosphere have invested heavily to determine these natural variations. The most common research involves drilling ice cores into the Greenland and Antarctic ice sheets and analyzing them. When the snow fell that would be compressed into ice, it trapped some air. The composition of that air contains information on both the carbon dioxide concentrations at the time as well as the temperature that can be obtained by using oxygen isotopes. These cores yield detailed information on carbon dioxide level in the atmosphere for the past 100,000 years or more. The temperature information, however, is only at the Poles and may not reflect changes at the middle latitudes. Global warming cannot be correlated with carbon dioxide without additional data.

Climate data for the middle latitudes are not readily available because the surface is constantly reworked at the oceans. Lakes yield a much more continuous and undisturbed record of the climate

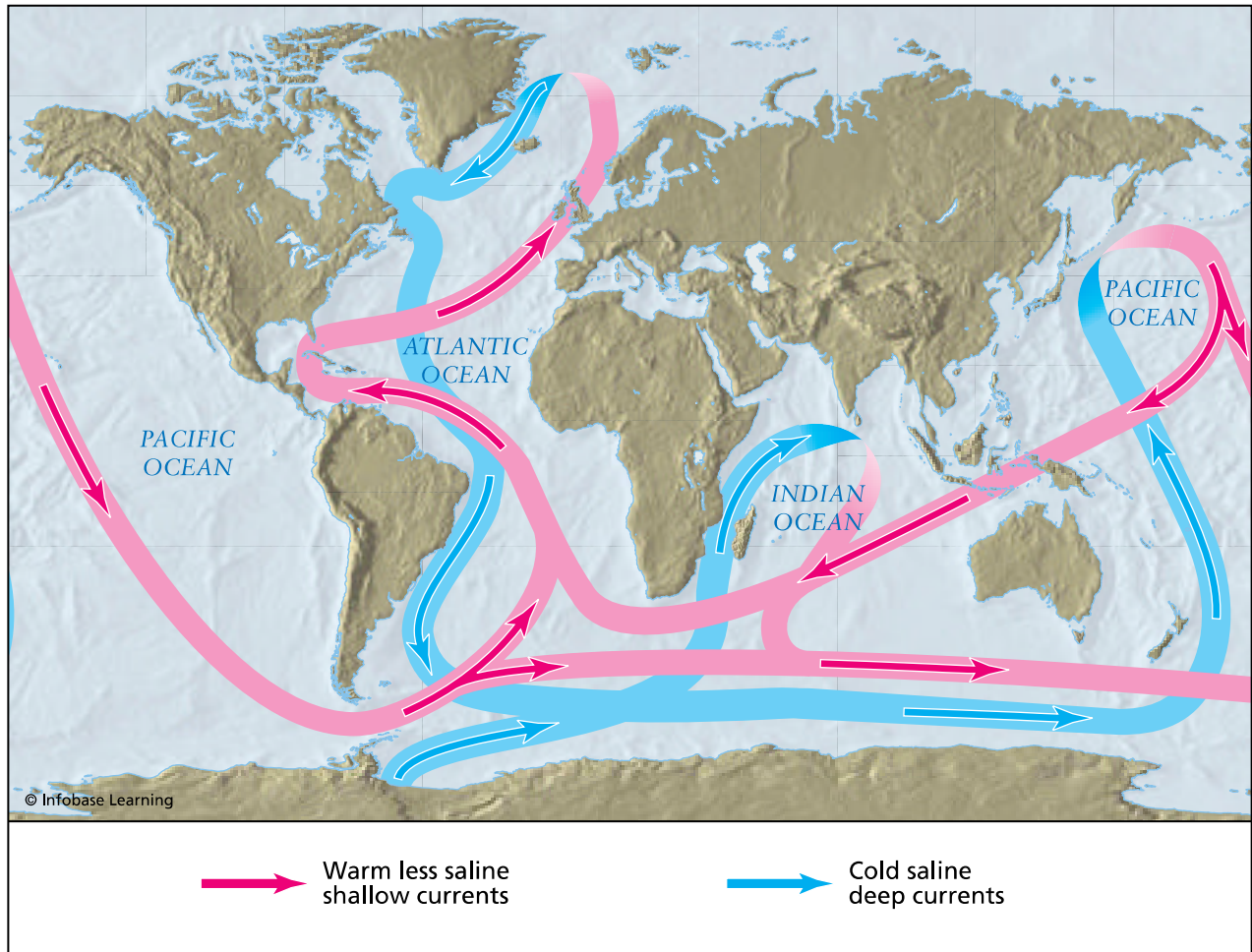
than oceans. The first real study of climate variations over extended periods was conducted on the Newark Basin in New Jersey. The Newark Basin was deposited between 200 and 225 million years ago when the Atlantic Ocean opened: It formed in a large rift valley that contained very large lakes. Depending upon climate, the water level of the lakes varied, and lakes even dried up in extended periods of dry climate. These rocks are probably the longest continuous sequence of nonmarine deposition in the world. The idea was that they could indicate the natural variations in the Earth's climate over a long period.

A continuous core of rock was drilled completely through the rocks of the Newark Basin and studied. The analysis included chemistry, physical character, fossils, magnetism, and several other pieces of data that were all integrated to show the variations in lake levels, sedimentation rate, vegetation, and other quantities that reflect climate variations. Using a polynomial fitting and analysis of the climate graphs that were produced, several orders of climate change cycles were identified. Many of these cycles are astronomical in origin and are called Milankovitch cycles after a famous mathematician who studied cyclical functions. Others reflected changes in sea level, ocean circulation, and other internal variations. This study became the first extensive baseline for climate variability in the midlatitudes.

More recently, cores have been and are being drilled in the deep lakes of the east African Rift system. Although drilling a continuous core of sediment and retrieving it from the rugged and poorly accessible Lake Tanganyika and Lake Malawi are difficult, the information will be even more useful. The problem with the Newark Basin data is that they could not be correlated with the ice core data. These new analyses will give us a much better picture of whole-Earth changes in climate.

### CURRENT EFFORTS TO REDUCE GLOBAL WARMING

There have been numerous local and several worldwide attempts to reduce carbon dioxide as well as several other air pollutants. The first international congress to address global environmental issues was the 1972 United Nations (UN) Conference on the Human Environment in Stockholm, Sweden. It was a breakthrough at the time that environmental issues could even be considered by an international group of such stature. Many issues were discussed at the conference, including greenhouse gases and global warming, but little was accomplished in the ensuing



**Map of the Earth showing the distribution of deep cold ocean currents (blue) and shallow warm ocean currents (pink). Locations where they change from blue to pink indicate upwelling, and where they change from pink to blue, surface water is sinking.**

years and conditions worsened considerably. Concern over this continuing environmental degradation led the UN General Assembly to convene the 1983 World Commission on Environment and Development. The report of this commission (known as the Brundtland Report) was a catalyst for the 1992 UN Conference on Environment and Development (UNCCD).

The UNCCD, or Earth Summit, was held on June 3 and 4, 1992, in Rio de Janeiro, Brazil. The conferees of the Earth Summit agreed on a global blueprint for sustainable development called Agenda 21 and on two sets of principles, the Rio Declaration on Environment and Development and the Forest Principles. This agenda included a multinational pledge to reduce emissions of greenhouse gases to 1990 levels by the year 2000. The idea was that developed nations, which produce three-fourths of the world's pollution, would investigate and develop new technology to reduce or reverse global warm-

ing. The beginnings of the Intergovernmental Panel on Climate Change (IPCC) were also a result of this conference. The problem was that negotiations with individual nations on central issues, such as population, energy, forest production, and consumption, made Agenda 21 relatively ineffective.

After the eventual success of the 1987 Montreal Protocol by the mid-1990s to reduce CFCs and protect the ozone layer, environmentalists attempted to gain a similar agreement with the Kyoto Protocol. To do this, the United Nations held a conference in Kyoto, Japan, in December 1997 and forged a document. The Kyoto Agreement, Treaty and Protocol is a program designed to reduce the total global emission of six greenhouse gases—carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons—averaged over the period of 2008–12 by 5.2 percent relative to 1990 levels. Limitations for individual countries range from 8 percent reductions for the European

Union and some others to 7 percent for the United States, 6 percent for Japan, 0 percent for Russia, and permitted increases of 8 percent for Australia and 10 percent for Iceland to induce them to ratify it. The initial agreement was signed between March 16, 1998, and March 15, 1999, but efforts to achieve complete world participation continue. As of June 2008, 182 parties had ratified the protocol, including 137 developing countries. The only major industrialized country that did not ratify the agreement was the United States because it was strongly opposed by the Bush administration. President Obama worked to have the agreement ratified by the United States when he took office.

One problem is that India and China, which are the most populous countries in the world and increasingly producing greenhouse gases, are not required to reduce hydrocarbon emissions but instead need only to monitor and report emissions. Both have ratified the agreement, as has Brazil, which is under the same constraints.

There is much confusion over what constitutes a real effort in curbing greenhouse gases, and true progress is slow to nonexistent. Even Al Gore's documentary *An Inconvenient Truth* has led to some confusion. He developed an idea about carbon exchange units and proposed essentially that planting a tree could offset hydrocarbon usage. In reality, a tree only temporarily sequesters carbon. If the tree is burned in a fireplace or allowed to rot on the surface, the vast majority of the carbon returns to the atmosphere. The only way to reduce carbon dioxide emissions is to reduce consumption of fossil fuels drastically. Indirect reductions such as the elimination of ocean pollution will also help. The situation, however, is quite dire.

See also CARBON DIOXIDE; GLACIATION; GORE, AL; IMPACT; EXTRATERRESTRIAL; OZONE AND CHLOROFLUOROCARBONS; PARTICULATE; REVELLE, ROGER; VOLCANOES.

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#### Gore, Al Albert Arnold Gore, Jr. (1948– ) American Politician, Environmental Spokesperson

Al Gore is one of the most prominent and controversial personalities in American politics and popular culture from the late 1980s to the present. Although he started out as a rather generic young politician, Gore made a decision to become an environmentalist, and, as a result, he has become the most effective spokesperson for the battle against global warming in the world. He did not initially focus so strongly on global warming; he first took up the efforts of Rachel Carson and battled chemical pollution and toxic waste, citing Carson as his inspiration. He was even called "Ozone Man" for his focus on the problems of chlorofluorocarbons (CFCs) and stratospheric ozone reduction. As an undergraduate student, however, he crossed paths with Roger Revelle at Harvard University, who is considered "the grandfather of global warming." Gore credits Revelle for introducing him to the problem with such passion that Gore has decided to take up the battle on more fronts and with more effectiveness than Revelle would have ever dreamed possible.

#### BIOGRAPHICAL INFORMATION

Albert Arnold "Al" Gore, Jr., was born on March 31, 1948, in Washington, D.C., the son of a U.S. congressman from Tennessee. Al Gore split his time between a farm in Carthage, Tennessee, in summers and in Washington, D.C., during the school year. He attended the exclusive St. Alban's Episcopal School for Boys and graduated in 1965. That fall he enrolled in Harvard University, where he was the roommate of the actor Tommy Lee Jones. Gore graduated in 1969 with a bachelor of arts degree in government with honors. He also married Mary Elizabeth "Tipper" Aitcheson that year. Although he could have avoided military service and was opposed to the Vietnam War, Gore chose to enlist in the U.S. Army on August 7, 1969, to fulfill his civic duty. He was sent to Vietnam on January 2, 1971, to serve for





**Al Gore speaks at the Grenelle de l'Environnement ecological talk at the Élysée Palace in Paris, France, October 2007**  
(Philippe Wojazer/Reuters/Landov)

five months as a field reporter. He returned to the United States in 1971 to enroll in divinity school at Vanderbilt University. He also accepted a position as a reporter for the *Tennessean*, the local Nashville newspaper. In 1974, Gore enrolled in law school at Vanderbilt University.

Al Gore's political career began in 1976, when U.S. Congressman Joe Evins announced his retirement after 30 years. Gore quit law school and, after winning the Democratic primary, ran unopposed for Tennessee's fourth district seat. He would later win reelection in 1978, 1980, and 1982. In 1984, Gore would win election as U.S. senator, succeeding Howard Baker. Al Gore ran for president in 1988 but finished second to Michael Dukakis in the Democratic primaries. In 1992, Bill Clinton chose Gore as his running mate, and they were elected and then reelected in 1996. Al Gore served as the 45th vice president of the United States from 1993 to 2001. Gore was the Democratic nominee for the presidency in the 2000 election and won the popular vote but was defeated in the electoral vote and lost

the most hotly contested election in recent history. Since then, Gore has served as visiting professor at Columbia University, the University of California at Los Angeles, and Middle Tennessee State University. He has also been involved with several investment companies and several business ventures. Gore continues to write books and even made a documentary on global warming. Although Al Gore decided not to run for president in 2008, it is unlikely that his career in public service, and as an advocate for the environment, is over.

### ENVIRONMENTALIST

Al Gore claims that his interest in environmentalism began at a young age. When Rachel Carson's book *Silent Spring* was published in 1962, it became a major topic of conversation in the Gore household. Although he was a supporter and instigator of efforts to protect the environment during his years as congressman and senator, Al Gore's real birth as an environmental spokesperson occurred in 1989, when

he wrote the environmental book *Earth in the Balance*. It was the first book written by a current U.S. senator to make the *New York Times* Best Seller List since John F. Kennedy wrote *Profiles in Courage* more than 30 years earlier. The book supported the entire environmental movement but especially the idea of greenhouse gases and global warming.

Al Gore was involved in several environmental efforts as vice president. In 1994, he helped launch the GLOBE project, a worldwide environmental-educational initiative that utilized the Internet, Gore's other major area of interest and fame. Gore strongly supported passage of the Kyoto Treaty of 1997, which established restrictions on carbon dioxide output. Although this project should have been a great victory, the U.S. Congress refused to enact it, leaving Gore open to criticism by environmental supporters, ultimately hurting him politically.

Al Gore has probably been a more effective environmental advocate and spokesperson since he left the vice presidency. These efforts culminated in the production of the documentary film and accompanying book *An Inconvenient Truth* in 2006. The theme of the work is the global climate change crisis and potential methods to combat it. The film won the 2007 Oscar (Academy Award) for a documentary feature and the 2007 Sir David Attenborough Award for Excellence in Nature Filmmaking at the Santa Barbara International Film Festival, among others. To date, it has become the documentary with the third-highest box office gross sales. The book has also made the best-seller list. Gore and his associates have crossed the country presenting the warnings of global warming to literally hundreds of audiences. He even addressed Congress as a private citizen. He helped organize the Virgin Earth Challenge, which provides a prize of \$25 million to any group or individual to present a viable way to remove greenhouse gases from the atmosphere, as well as the worldwide Live Aid Concerts on July 7, 2007, to help battle global warming.

Gore initiated several business ventures that encourage the reduction of greenhouse gases. He has been a great proponent of quantifying the carbon footprint of humans from the country to the individual level. The idea of carbon offset or exchange is that if people contribute carbon dioxide to the atmosphere, then they should plant a tree or do other things, such as drive an electric vehicle, to reduce an equivalent amount. This idea promotes environmental sustainability, though the global warming situation is nowhere near sustainability at this point. As a result of all of these efforts to call global warming to the attention of the public, Al Gore won the Nobel Prize in peace in 2007.

See also CARBON DIOXIDE; CARSON, RACHEL; OZONE; REVELLE, ROGER.

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**Greenpeace** The image that the name Greenpeace calls to mind is a small ship or boat manned by several activists and positioning itself in front of a much larger, more threatening vessel in order to prevent some action. Indeed, that is the image that Greenpeace hopes to project, and they have disrupted nuclear testing, whale hunts, and baby seal hunts with these nonviolent protests. Their mission statement is as follows:

Greenpeace is an independent, campaigning organization which uses peaceful direct action and creative communication to expose global environmental problems and to force solutions for a green peaceful future. Greenpeace's goal is to ensure the ability of the earth to nurture life in all of its diversity.

Greenpeace is the largest and one of the few successful organizations that are based on ideals of the radical 1960s. Greenpeace International now has an international membership of between 2.5 and 5 million people with an estimated \$360-million global empire and 27 national and regional offices in 42 countries. They have been labeled ecoactivists, ecoextremists, and ecoterrorists by supporters and detractors alike. Regardless of the political positioning and controversy that surround Greenpeace in virtually all of its efforts, it is made up of a large number of people who are truly concerned about the natural environment of the Earth and are willing to take action to protect it. Some activities of Greenpeace are certainly questionable, and their motivations have come into question, but, in general, Greenpeace has been one of the most effective organizations to protect the natural environment and provides great hope for continuing these actions in the future.

## THE HISTORY OF GREENPEACE

The Greenpeace organization began in 1969–70 in Vancouver, Canada, when a group of radical Americans from the antiwar group the Don't Make a Wave Committee (founded by James and Marie Bohlen) were joined by several Canadian activists in the basement of a Unitarian church to protest U.S. nuclear bomb testing. They planned to stop the test, code-named Cannikin, beneath Amchitka Island in the Aleutian Islands, Alaska, by putting themselves in harm's way in a small boat called the *Phyllis Cormack*. The U.S. Coast Guard scuttled the attempt, but it brought the core group together and galvanized their resolve. The *Phyllis Cormack* was called *Greenpeace I* by the members and a successor vessel was named *Greenpeace Too*. Early support was from the Quaker church, as several of the key members were in the Society of Friends and the group was aligned with the much better established Sierra Club prior to the trip to Amchitka. After that, the more radical Greenpeace organization grew ever further from the more conservative Sierra Club.

On May 4, 1972, the organization officially adopted the name *Greenpeace Foundation*. The yacht *Vega* was renamed the *Greenpeace III* that same year, and it participated in a protest against the testing of French nuclear devices in the atmosphere at Mururoa, French Polynesia, but was unsuccessful. The boat *La Flor* set out from Melbourne, Australia, to disrupt testing in 1974 and was dubbed *Greenpeace IV* but was also unsuccessful. That same year, the Vancouver-based group initiated their famous antiwhaling campaign and encountered whaling vessels from the Soviet Union off Mendocino, California. They had another encounter with the Soviet whaling fleet in 1976 in the ship *James Bay*, which was renamed *Greenpeace VII*, with much greater success as the result of better information and funding. It is the picture of a small boat full of angry protesters facing down a huge Soviet whaling boat that comes to mind for most people when they think of Greenpeace. The year 1976 was also historic for Greenpeace because they launched another high-profile campaign against the beating and killing of seal pups in Newfoundland just for their skins. The skins were used in the high-fashion garment industry, and the campaign received extensive publicity in the media, especially when Brigitte Bardot joined Greenpeace in the effort.

After the original Vancouver-based Greenpeace group encountered financial difficulties and disputes over operations, David McTaggart seized the opportunity to develop a new structure for the organization. After extensive lobbying efforts, on October 14, 1979, Greenpeace International unified the for-

merly independent Greenpeace offices under a single umbrella that would determine the overall direction of the organization. Although there was much criticism from both within and outside the organization that Greenpeace had become similar to the hierarchical organizations it was fighting, the new reorganization allowed initiatives to be much better orchestrated. Another big change in Greenpeace at this time was the purchase of the much larger fishing trawler *Sir William Hardy*, which was completely restored and refitted before being renamed the *Rainbow Warrior*. With this large vessel, Greenpeace could gain much more attention and be more effective in their efforts. The *Rainbow Warrior* was used extensively between 1978 and 1985 in non-violent direct action against ocean dumping of toxic materials and nuclear waste, the gray seal hunt in Orkney, and nuclear bomb testing in the Pacific region, among many others.

In 1985, the *Rainbow Warrior* returned to the Maruroa atoll where France tested its nuclear devices. While it was in a New Zealand harbor, France planted demolition devices on the boat and blew it up, sinking the *Rainbow Warrior* and killing a Dutch freelance photographer who was aboard. Although Greenpeace lost its famous ship, the publicity put the organization back in the limelight but this time as a victim of an unprovoked attack from an evil French government. It was a great boon to their image and rejuvenated their membership. As a result, France was forced to pay fines to New Zealand and the family of the photographer. It was also the last straw for New Zealand, which passed legislation in 1987 to declare itself a nuclear-free zone, thus making it very difficult for France to mount nuclear testing in the area.

Greenpeace commissioned a second *Rainbow Warrior*, in 1989, which remains active today. In 1996, the *MV Sirius*, another Greenpeace vessel, was detained by Dutch police but released soon afterward. Nonetheless, it again put Greenpeace back in the public eye. Other current ships include the *Arctic Sunrise*, *Esperanza*, *Witness*, and *Billy Greene*. Greenpeace has offices in Argentina, the Australia-Pacific region (Australia, Fiji, Papua New Guinea, Solomon Islands), Belgium, Brazil, Canada, Chile, China, Czech Republic, France, Germany, Greenpeace Nordic (Denmark, Finland, Norway, Sweden), Greece, Greenpeace Central and Eastern Europe (Austria, Hungary, Slovak Republic, Poland, Romania, Bulgaria, Slovenia, Serbia, Montenegro, and Bosnia, with no permanent campaign presence in the latter five states), India, Italy, Japan, Luxembourg, Greenpeace Mediterranean (Israel, Cyprus, Lebanon, Malta, Tunisia, Turkey), Mexico, the

Netherlands, Greenpeace Aotearoa New Zealand (New Zealand), Russia, Southeast Asia (Philippines, Indonesia, Thailand), Spain, Switzerland, the United Kingdom, and the United States.

### CURRENT ACTIVITIES

Greenpeace has priority areas where their efforts are concentrated. These priority areas are determined at the central headquarters in Amsterdam, the Netherlands, by vote of the regional offices and indeed the entire membership. There is never full agreement on all issues and some offices put more effort into some priorities than others. There are also local priorities that a particular office may emphasize but that may not be global priorities per se. The current priority areas are listed in the following.

#### Stop Global Warming

This effort is primarily one of petitioning legislative bodies and public education. The efforts are intended to persuade the U.S. Congress both to support legislation that would reduce greenhouse emissions and to switch oil subsidies to renewable forms of energy such as solar and wind technology through a letter-writing campaign. The other effort is to persuade people to stop purchasing automobiles that are not efficient, particularly sport utility vehicles (SUVs) and pickup trucks. Greenpeace uses its legal connections to try to force change through court cases to lobby elected officials. The lobbyists have made some headway but primarily in countries other than the United States. They made great efforts to gain support for the 1997 Kyoto Protocol and were instrumental in inducing many countries to ratify it.

#### Oceans

Greenpeace has traditionally emphasized and been most effective with issues related to the oceans. Efforts are still being made to eliminate whaling through direct action. Although Greenpeace has made significant headway in reducing whaling, some countries still engage in it. Most recently, Greenpeace confronted the Japanese whaling fleet and scuttled their attempts to take whales. They are also involved with the prevention of overfishing by the fishing industry and ocean dumping of both garbage and industrial waste. In addition to whaling and simply taking too many fish from the ocean, Greenpeace is actively opposed to factory fishing and large-scale industrial practices, bottom trawling that destroys coral reefs and takes potentially endangered species, by-catches of unintended fish and mammals, and ocean farming, which is apparently inefficient. Their work is both physically confrontational with

the fleet of ships and legislatively oppositional. They also have public educational campaigns to reduce plastic waste from the oceans simply by reducing litter and recycling.

#### Forests

All of the efforts that have gone into saving forests over the years have given environmentalists the nickname "tree huggers." Although in many areas there has actually been an increase in forestation over the past few decades, in many critical areas, deforestation continues unabated. Greenpeace is actively pursuing a program to stop deforestation in the tropical rain forest of the Amazon basin. They are raising a large sum of money to provide financial incentives as well as working with legislators to stop deforestation by 2015. The Greenpeace Jaguars, however, are a group of people on dirt bikes who roam the Argentine forests looking for bulldozers to menace. The rain forest effort is largely being orchestrated by the Brazil office. Another initiative is to have deforestation included in treaties such as the Kyoto Protocol to reduce greenhouse gases. Other areas of concerted efforts are Alaska forests, Indonesian forests, and a boycott of palm oil. It seems that in many areas, rain forests and especially peatlands are cleared to plant palm oil plantations. Both of these actions contribute to global warming.

#### Nuclear

Greenpeace's efforts regarding nuclear energy are on two fronts: reducing nuclear energy and disarmament. Greenpeace began attempting to block nuclear testing, and it is indeed a legacy of the organization that through several far-reaching treaties, nuclear testing is essentially nonexistent, although not completely banned. The more than 2,000 nuclear weapons tests that have already occurred have left global and regional contamination. Even with all of the dismantling of the nuclear arsenal in recent years, there are still nearly 36,000 nuclear weapons around the world with thousands on standby alert. There are 500 nuclear reactors aboard submarines. Many emerging countries such as Iran are attempting to develop nuclear capability as well. Greenpeace is actively attempting to influence legislators to reduce the nuclear arsenal. It is also fighting the operation and construction of nuclear power plants primarily because of the cost, the danger of an accident such as those at Chernobyl and Three Mile Island, and the potential targeting of nuclear power plants by terrorists. They are also using the disposal of high-level nuclear waste as a deterrent, though not as forcefully. Most of the efforts are in public education and attempts to influence legislators.



### Toxics

Greenpeace is addressing not only the overuse of toxic industrial chemicals, but also the location of chemical plants. Ever since 9/11, potential terrorist targets have been identified and evaluated for their vulnerability to attack, including chemical plants. The U.S. Environmental Protection Agency (EPA) has shown that the presence of more than 100 chemical plants in the United States threatens the safety of 1 million or more people in an area up to 25 miles (40 km) away from a plant. Further, the U.S. Naval Research Laboratory estimated that at least 100,000 people could be killed or injured in the first 30 minutes if any of these plants or even a train carrying chlorine gas or another toxin were successfully attacked by terrorists. Greenpeace has lobbied legislators to reduce this threat, with positive results. Greenpeace is also addressing the pollution problem posed by the disposal of old electronic devices (also known as e-waste). These devices primarily contain heavy metals and plastics, but some can contain dangerous organic fluids and even radioactive sources. The primary efforts to address the problems are in public education

and lobbying the electronics industry. They are encouraging Apple Inc. to be the green leader in this effort.

### Genetic Engineering

One of the latest efforts by Greenpeace is to fight the introduction of genetically engineered food (or “frankenfood,” as it has been called) into consumer products. They feel that genetically engineered (GE) food is not tested rigorously enough and, as such, could pose serious potential health threats of unknown proportions. Greenpeace was involved with the recall of the GE corn that mistakenly made its way into the market in 2006. The first step is to have companies label food that contains GE products. Even then, because livestock is fed GE grains, people are still being exposed to it.

*See also* CHERNOBYL NUCLEAR DISASTER; GLOBAL WARMING; INORGANIC POLLUTANTS; SIERRA CLUB; THREE MILE ISLAND; WAR AND POLLUTION.

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Frozen artesian well, Letchworth State Park, New York. In some winters, the ice cone can be more than 60 feet (18.3 m) tall. (Edward Kinsman/Photo Researchers, Inc.)

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**groundwater** When meteoric water precipitates from the clouds to Earth, it has several potential paths. It can simply become surface runoff and

flow to the nearest downhill stream in the drainage basin. It can also be stored on the surface as snow and ice or in a swamp or vernal pool or any number of biologic or anthropogenic sinks. Some water can simply evaporate and return to the atmosphere. None of these paths, however, directly contributes to the groundwater supply; only water that infiltrates the soil or rock forms subsurface water and groundwater.

Infiltrating water penetrates the surface and enters the vadose zone, which only contains water during precipitation, flooding, and melting events. The rest of the time it contains only gas (primarily air) in the pore spaces. Water passes through this unsaturated or partly saturated zone until it encounters water-saturated soil, sediment, or rock. The top of this saturated, or phreatic, zone is called the water table. Once it enters the phreatic zone, water becomes part of the groundwater system and flows primarily in response to gravity similarly to surface water but much more slowly.

In all rural and many suburban settings, all household water and even much of the industrial water



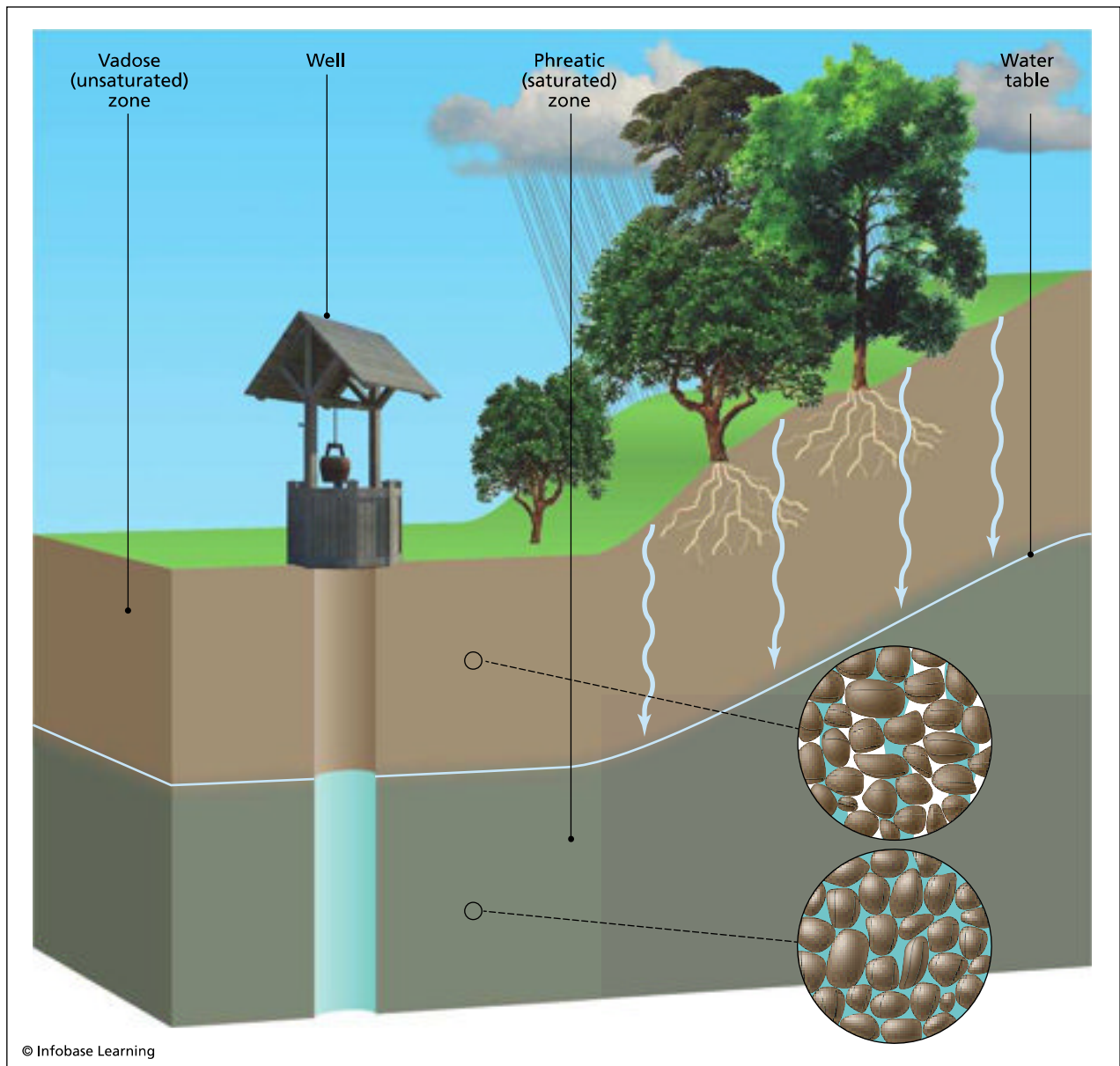
Two groundwater professionals sample and test groundwater from a monitoring well. Many groundwater professionals are members of the Association of Ground Water Scientists and Engineers, a division of the National Ground Water Association ([www.ngwa.org](http://www.ngwa.org)). (National Ground Water Association)



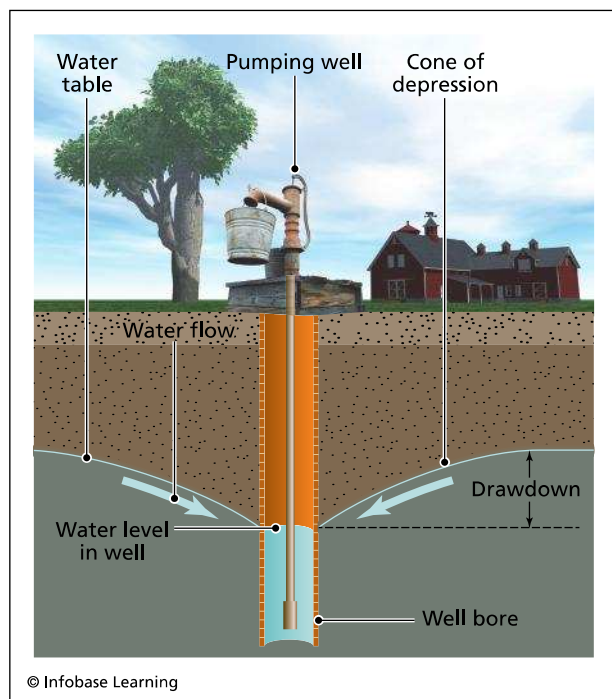
is drawn from the groundwater system through a well. In former times, people just dug a hole until it penetrated the water table and phreatic zone. Water was drawn from this shallow zone using a bucket or hand pump. The problem with this method of obtaining water is that the water table is so close to the surface in most populated areas that it is polluted with any number of point and nonpoint pollutant sources. In addition, with the heavy usage in these areas, the level of the water table can fluctuate so much that these wells can run dry at any time. For this reason, most people drill deep wells ranging

from tens to thousands of feet to find reliable sources of drinking water.

Surface water may infiltrate the ground beneath it at any time or in any place and become part of the groundwater system. In some places, the topography drops to a lower elevation than the water table. In this case, springs of flowing water emerge. In this way, groundwater may contribute to the surface water system. In other areas, a small lens of clay or other aquiclude material may trap the infiltrating water in a small underground pool that is above the regional water table. This small feature is a perched



**Illustration of the groundwater distribution in the shallow subsurface with a hand-dug water well and insets of water saturation. The soil pores in the shallower vadose zone (above the water table) are only filled with water as it is infiltrating down from the surface and are otherwise filled with gas. The soil pores in the phreatic zone (below the water table) are always filled with water.**



**Illustration showing that the water table is drawn down around an actively pumping well, forming a cone of depression on it. The water table returns to a flat surface when the well stops pumping.**

water table and can account for significant water supplies in some areas.

See also AQUIFER; ORGANIC POLLUTANTS.

**Gulf War oil spills Kuwait January–February 1991** *Air, Water, and Soil Pollution* One of the most vivid images of Operation Desert Storm, or the Gulf War, as it is also known, is of the thick, billowing, black smoke clouds emanating from the giant flares shooting hundreds of feet in the air from the sabotaged Kuwaiti oil wells. It was the biggest oil spill that ever occurred in the world and perhaps the worst environmental disaster. Ecologically, the area may never recover from pollution caused by all of the spilled oil and soot tar from the partially burned oil. It is almost beyond comprehension that this disaster was purposefully caused. The images were so striking that they were used in several popular movies. Most notable of these is *Jarhead*, which shows many aspects of the fires and fallout.

### BACKGROUND

On August 2, 1990, Iraqi armed forces invaded Kuwait, ostensibly to reunite this country with Iraq after the illegal separation of the two nations by the British in 1913. Most experts agree, however, that

the true underlying causes for the invasion were Kuwait's insistence on the repayment of the \$14-billion Iraq had borrowed to finance its eight-year-long war with Iran and economic incentives associated with the annexation of Kuwait's massive oil reserves. Within a few days of the Iraqi invasion, Kuwait's relatively small army had been destroyed, its government was dissolved, and its monarchy was in hiding or exile. It took the United States, working through the United Nations, about seven months to build enough international support among Iraq's Arab neighbors, Russia, China, and Western European countries to muster the use of force to expel Iraq from Kuwait. The first step in that process, the air war, began early in the morning on January 17, 1991, and lasted almost 40 days. On February 24, U.S. and international coalition forces began their land offensive, which ended three days later with Kuwait liberated and the Iraqi army in headlong retreat to their own country.

War has always had environmental consequences, some intentional and some not. In 1672, in order to slow the advance of a French army, the Dutch opened their dikes and intentionally flooded much of their country. While they were successful in staving off the French, the flooded land had been contaminated with salt water and could not be farmed until many years later. China, in 1938, purposefully destroyed the Huayuankow dike on the Yellow River near Chengchow with the intention of trapping and killing several thousand Japanese soldiers billeted in that area. Unfortunately, these same floods also killed tens of thousands of Chinese citizens. Oil spills along the East Coast of the United States at the start of World War II were commonplace as German U-boats sank merchant vessels carrying fuel and other supplies to the British, and the environmental legacy of the U.S. nuclear arms race can be seen at numerous contaminated military bases and manufacturing facilities across the nation. In Southeast Asia, by 1983, the use of the herbicide Agent Orange had contaminated about 50 percent of Vietnam's forests and arable land, many of which today are still struggling to return to productive use.

### POLLUTION OF THE AREA

Shortly after the international coalition began its air war against Iraq, the Iraqi army scuttled five oil tankers moored at the port of Mina Ahmadi, Kuwait's main oil shipping facility, and then blew up an offshore oil loading terminal on Sea Island, another major oil transfer and tanker embarkation point. Both actions created very large oil slicks in the Persian Gulf, almost twice the size of the world's



previous largest slick, the Ixtoc I oil well blowout in the Gulf of Mexico. As coalition air attacks continued into February, the Iraqi army maintained their program of intentional environmental degradation, damaging oil distribution centers in Abu Halifa and Shuaiba and bypassing safety systems on land-based wells so that oil would gush to the surface and form enormous oil lakes or pools. Unlike in the historical examples, there was no strategic or military advantage that Iraq obtained by fouling Kuwait's coastline, soil, or atmosphere: The coalition forces' air war did not stop, the land invasion was not delayed nor its objectives changed, and international opinion did not suddenly begin to favor Iraq.

The oil slick created by the release of an estimated 11 billion barrels of oil (440 million gallons [2.1 billion L]) from coastal terminals and land-based oil wells contaminated a 300-mile- (483-km-) long stretch of beach along the northern coast of Saudi Arabia. Salt marshes, mangroves, coral islands, and other important wildlife habitats and breeding grounds were destroyed, and more than 30,000 seabirds were killed, along with thousands of shorebirds. The local fishing industry was shut down, as oil could be seen from horizon to horizon across much of the gulf in this area. It was only through quick action by the Saudi Arabian government that oil was prevented from entering the intakes of its largest desalinization plants, which supply 40 percent of its potable and industrial freshwater.

Although the extent of the damage caused by the Gulf War I oil slicks is still being evaluated, many experts are convinced that the environment in this area will be unable to recover and that a significant and permanent reduction in species diversity has occurred. What this means for the ecosystem in the Persian Gulf as well as other, worldwide ecosystems is not clearly understood. Despite the severity of the long-term damage from the oil slick, it was quickly overwhelmed by short-term impacts from the oil well fires.

Kuwait operated an inventory of approximately 1,100 preinvasion land-based oil wells. As the Iraqi army fled Kuwait, it set fire to about 850 of them. The wellheads were dynamited, and oil gushing into the air was set ablaze by the explosion. In some cases, the oil oozed to the surface and saturated the sand around fractured casings and caught fire, forming blazing lakes or pools of fire. Several hundred million gallons of oil were released in this manner, and, at the peak of the fires, Kuwait's economy lost \$2,500 every second. Eventually, almost one-third of Kuwait's surface area was covered by a layer of oil, ranging from a thick, asphaltic material near the well-field fires to a tarry crust downwind of them.

The oil well fires dumped hundreds of tons of particulate, sulfur dioxide, and potentially carcinogenic polycyclic aromatic hydrocarbons (PAHs) into the atmosphere. This airborne pollution was deposited across Kuwait as well as southern Iran and parts of Pakistan and northern India. Black snow was reported in the Himalayas, and the smell of oil could be detected more than 1,000 miles (1,600 km) downwind of Kuwait. Similarly to ecosystem effects, long-term health consequences on the Kuwaiti people or coalition forces exposed to these hydrocarbon residuals are not well understood. Gulf War syndrome, a name given to a collection of diseases and other disorders, including certain types of cancer and brain damage, suffered by U.S. and other troops who served in Kuwait, is thought to be related, in part, to exposure to smoke and chemicals from oil field fires.

### EXTINGUISHING THE FIRES

When efforts to extinguish the fires began, there were 613 burning wells, 76 wells gushing oil, and a total of 788 damaged oil wells. Fires from the burning wells shot flames like blowtorches hundreds of feet into the air. Dense smoke clouds reached into the sky to heights of 0.63–2.5 miles (1–4 km) and extended downwind for hundreds of miles. Around some of the fires, the desert was covered with a black crust, and ponds of oil formed around many of the damaged wells, posing a threat of ground-level fires and pollution of groundwater. A black, oily rain fell from the oil well fires, and there were unexploded land mines, bombs, and shells everywhere. This hostile environment, coupled with the lack of adequate technology, and compounded by shortages of water, electric power, and locally available equipment, made it impossible to extinguish the fires quickly.

The first companies to attempt to extinguish the Kuwaiti oil well fires and cap the wells were the internationally famous Red Adair, Boots and Coots, Safety Boss, and Wild Well Control, Inc., from the United States. OGE Drilling-Kuwait, Inc., coordinated the multiple firefighting teams. The four companies began firefighting activities on March 16, 1991, but after several months of slow progress, the Kuwaiti government decided to enlist more help. Santa Fe Drilling Company joined the effort as the number of firefighting companies grew. By the end of August, firefighting teams from France, Hungary, China, Iran, the USSR, and the United Kingdom had joined in the efforts.

By September 1991, the number of firefighting companies in Kuwait had reached 27. This increased effort led to an increase in the average number of wells capped per day from three in May 1991 to

eight in October 1991. By October 10, firefighters had capped 566 of the damaged wells. By November 9, 1991, all burning wells had been extinguished and all gushing wells had been capped.

The oil well fires were so intense and flowing so fast that firefighters were forced to develop and implement innovative firefighting techniques quickly. In early April 1991, the first fires addressed were extinguished by using seawater. The huge amount of seawater that was needed was taken to the fires from the Persian Gulf through a converted oil pipeline at a rate of 4,000 gallons (15,200 L) per minute. Another innovative method was “raising the plume.” In this case, a metal casing 30–40 feet (9.2–12.3 m) high was attached to the blown wellhead to raise the flame. Liquid nitrogen or water was pumped into the casing to reduce the oxygen supply to the fire. Yet another innovation was to drill “relief” wells into the main burning wells. The relief wells diverted part of the flowing oil and gas and reduced the pressure at the main well, allowing it to be extinguished and capped more easily. Dynamite was even used to relieve wellhead pressure in some instances. One of the most unconventional methods devised

involved the mounting of Mig-21 turbine engines on old Soviet T-62 tanks to shoot high-pressure water and air at the burning well. This method, devised by the Hungarian team, proved to be fairly popular.

See also DESERTS; IXTOC I OIL SPILL; OIL SPILLS; PAH; PARTICULATE; SULFUR DIOXIDE; WELLS.

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# H

## **Haiti    deforestation    Haiti 1980–present**

**Water Pollution** Hispaniola, which was Christopher Columbus’s first landfall in the New World, lies in the northern Caribbean. The island has four separate ecological settings, with about half of its eastern and northern land area historically covered by dense growths of pine, extending to elevations of higher than 6,000 feet (1,829 m) above sea level, thanks to the rich soil, plentiful rain, and mild climate. Also present in the rain shadow in the southern and western portion of Hispaniola is a dry forested region making up about 20 percent of the island, and more pine forest covers the other mountainous parts (approximately 15 percent) of the island. The lowlands are dominated by marshes, flooded grasslands, and savannas surrounded by lakes and lagoons.

Just as the island’s ecological regions are readily distinguishable, so are its political subdivisions. The Republic of Haiti controls the western third of Hispaniola, and the Dominican Republic governs its eastern two-thirds. Haiti was a former colony of France that grew into a republic, declaring its independence in 1804. Haiti’s political institutions have long battled to establish and maintain themselves against external meddling by Germany, Spain, and the United States, as well as their own national army and pervasive internal corruption. Currently, Haiti is a presidential republic, whereby the president is the head of state, while a prime minister manages the government.

The history of the Dominican Republic is not much different. It too threw off the yoke of colonialism in 1844. After briefly rejoining the Spanish empire, in 1865 the Dominican Republic finally achieved its independence. Since then, it has endured invasions by the United States (1916 and 1965) and

slow economic growth limited by a lack of natural resources and a low-yield agricultural system. More recently, the tourism and service sectors of the economy have greatly expanded, and the Dominican Republic has emerged as a developing country with a growing middle class. Further economic expansion may be difficult to sustain, however, unless the country can solve its chronic energy shortages. Similar to Haiti, the Dominican Republic is a democratic republic, where the president is both head of state and head of government. Legislative power lies with an executive branch and the two chambers of the national congress.

## **BACKGROUND**

In general, the Dominican Republic has been the more politically stable of the two. Since the mid-1960s, a system of national parks and preserves has been established and remains in existence today. It is these parks and woodlands, many of which are owned by politically connected private individuals, together with the many unspoiled beaches of the Dominican Republic, that help make this part of Hispaniola an attractive and desirable place for its 9.1 million people to live and do business, and for foreigners to vacation. In Haiti, the higher population density and more fragile political system have placed enormous stress on the local ecology.

Charcoal, one of the principal energy sources in Haiti, is made up primarily of impure carbon and is derived from the removal of water and other volatile constituents from wood. This process involves heating or cooking the wood in oxygen-deficient atmospheres in specially built ovens or earthen kilns. Charcoal (meaning “turn to coal,” a reference to its



**Denuded Haitian landscape (left) compared to Dominican Republic's forests (right), south of Dajabon, Dominican Republic (James P. Blair/National Geographic/Getty Images)**

dark color) also can be made from sugarcane and animal bones. Lightweight, soft, and easily broken, charcoal is 85–95 percent carbon, with residues of ash and other compounds. Charcoal burns hotter (930–1,290°F [500–700°C]), longer, and cleaner than wood (390–750°F [200–400°C]) or coal. Its manufacture, however, is terribly inefficient, especially when done on a cottage industry (“low-tech”) basis. Modern industrial charcoal operations yield about 90 pounds (41 kg) of charcoal for every 100 pounds (45 kg) of wood. When it is done locally, by inexperienced or poorly equipped individuals, recovery rates can drop to 50 pounds (23 kg) of charcoal for every 100 pounds (45 kg) of wood or even less. The process also produces significant air pollution including particulate (smoke), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide, and carbon dioxide, and many others depending upon the wood used.

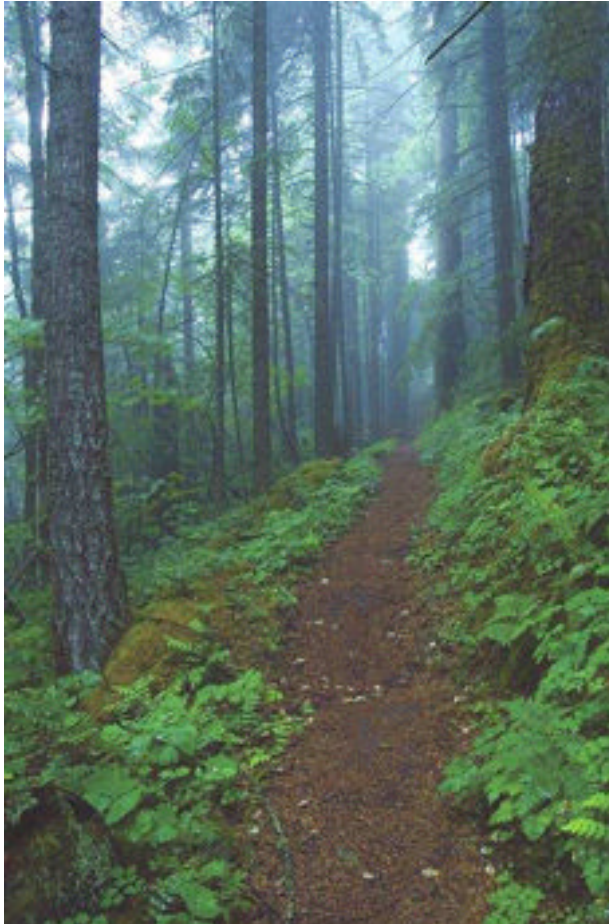
### DEFORESTATION

Hispaniola has no deposits of oil, natural gas, or coal and must import almost all of the raw materials necessary for energy production. The improving eco-

nomic conditions in the Dominican Republic allow it to meet most of its basic energy needs, whereas impoverished Haiti has great difficulty finding the money to pay for the fuel needed to keep electricity flowing. As a result, biomass fuels such as wood, charcoal, and other organic materials derived from plants and animals have become Haiti's primary energy sources, especially for cooking in rural areas and by the urban poor. This fuel, however, exacts a heavy ecological price. In the early 1920s, almost 60 percent of the Haitian countryside was forested. Today, the landscape has been denuded of trees and vegetation as people have scrambled to collect fuel. Approximately 98 percent of Haiti's forests have been cut down, and the smuggling of wood from protected areas within the Dominican Republic is becoming a serious threat to that country's ecology.

With the removal of the trees, soil is quickly washed away, and agricultural productivity in Haiti has dropped severely. In addition, the use of tree, crop, and animal residues (manure) for fuel prevents these materials from acting as needed soil nutrients, further reducing crop yields and limiting the land's ability to support livestock. Besides soil erosion, the deforestation of Haiti has resulted in catastrophic





American temperate climate rain forest in Oregon (Justin Krug, 2008; used under license from Shutterstock, Inc.)

flooding and landslides. It has also resulted in siltation pollution of the rivers. On September 17, 2004, tropical storm Jeanne struck the north coast of Haiti, triggering a series of devastating mudslides and floods. More than 3,000 people were killed, mostly in Gonaïves, where every building was damaged and more than 200,000 were left homeless. Even though it was a major storm, Haiti has experienced worse rains than those from Jeanne in the past with much less loss of life and property. With trees and other vegetation not available to hold the soil in place, the hillsides surrounding Gonaïves first became quagmires and then fast-moving mud and debris that buried everything in their path.

Two-thirds of all Haitians survive by small-scale subsistence farming, and, with so many so dependent on the land, it could be considered puzzling that deforestation is occurring at such a rapid rate. People, however, desperately need the wood to cook their food and to earn a living by selling charcoal. Haiti is the poorest country in the Western Hemisphere, with 80 percent of its population living in

deplorable poverty. Unemployment is more than 60 percent and the average annual income is only a few hundred U.S. dollars.

### ADDRESSING THE PROBLEM

Since the early 1980s, when deforestation was first recognized as a major threat to the sustainability of life in Haiti, the U.S. Agency for International Development and other governmental and nongovernmental organizations have planted more than 60 million trees, which the Haitians cut down at a rate of about 15 million per year. Replanting projects sponsored by the United Nations, World Bank, and other relief organizations are ongoing, and programs try to promote the use of more efficient stoves and alternate cooking fuel (e.g., propane and solar). The root of the problem is financial. Haiti's forests will not return until its citizens are rescued from poverty and given the tools to rebuild their island's economy.

See also CARBON DIOXIDE; CARBON MONOXIDE; DESERTIFICATION; MASS WASTING; PAH; PARTICULATE.

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### Hanford Reservation Richland, Washington 1940s–present Soil and Water Pollution

On December 2, 1942, the famous nuclear physicist Enrico Fermi's team of scientists and engineers, working in a laboratory under the foot of stadium bleachers at the University of Chicago, demonstrated that when a uranium atom undergoes fission (splits), it produces energy and excess neutrons. These neutrons can be used in turn to split more uranium atoms in a self-generating chain reaction. This process would become the foundation upon which America's



**N-Reactor Complex on the Columbia River at the Hanford Atomic Reservation in Richland, Washington, ca. 1978**  
(© Bettmann/CORBIS)

nuclear program was built. This discovery occurred during World War II, and the Allies were concerned that the Nazis would be the first to harness atomic power for use in weapons of mass destruction. It was for this reason that President Franklin D. Roosevelt commissioned the Manhattan Engineering District (MED) to build an atomic bomb before Germany. Employing more than 130,000 people at its peak and costing more than \$27 billion (in 2010 dollars), the infrastructure of the Manhattan Project operated in the following three main facilities:

1. Los Alamos, New Mexico (code named Site Y). This was the main research and design branch of the Manhattan Project and served as its command and control center. The final assembly of the bombs dropped on Nagasaki and Hiroshima was performed at Los Alamos from component parts produced at other sites.
2. Oak Ridge, Tennessee (code named Site X). This 60,000-acre (24,281-ha) facility was developed to produce enriched uranium by gaseous diffusion and conducted plutonium production research. During World War II, it consumed almost 20 percent of all electricity generated in the United States. Natural uranium is made up of three isotopes, U-238 at 99.284 percent, U-235 at 0.7

percent, and U-236 at <0.001 percent. U-235 is the only substantially naturally occurring isotope of uranium that is fissionable by neutrons at critical mass in the proper arrangement. Enriched uranium is defined as uranium having a concentration of U-235 isotope greater than its natural occurrence. Highly enriched, or weapons-grade, uranium contains a U-235 concentration greater than 85 percent.

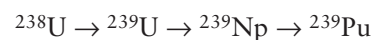
3. Hanford, Washington (code named Site W). Located near the Columbia River, this almost-700-square-mile (1,813-km<sup>2</sup>) facility produced the plutonium for the Hiroshima bomb as well as most of the plutonium contained in the 60,000 other atomic weapons that eventually formed America's atomic arsenal.

As the arms race expanded during the cold war, a second plutonium production facility, the Savannah River Site, was built in South Carolina in the 1950s. These four facilities became the lifeblood of America's nuclear program during the cold war and operated as small cities on 24-hour-per-day production status. If the nuclear deterrent was the reason that there was never a direct war between the United States and Soviet Union, the efforts of these federal nuclear facilities provided that deterrent.

### CONTAMINATION ISSUES

Uranium was the fissionable material used in the first atomic bomb dropped on Hiroshima, and the separation and concentration of U-235 from natural uranium entailed an elaborate and expensive process. While this work went on at Oak Ridge, a second source of fissionable material was sought that could be made faster, less expensively, and more simply. Site W at Hanford, 20 miles (32.2 km) from Yakima, Washington, was chosen by Army General Leslie Groves as the place to build the first plutonium production facility in the United States.

Plutonium occurs naturally only in trace quantities, but if uranium is bombarded with neutrons, it is formed through a beta decay process (conversion of a neutron in an atom's nucleus into a proton and electron) that first forms neptunium and then plutonium by the follow reaction:



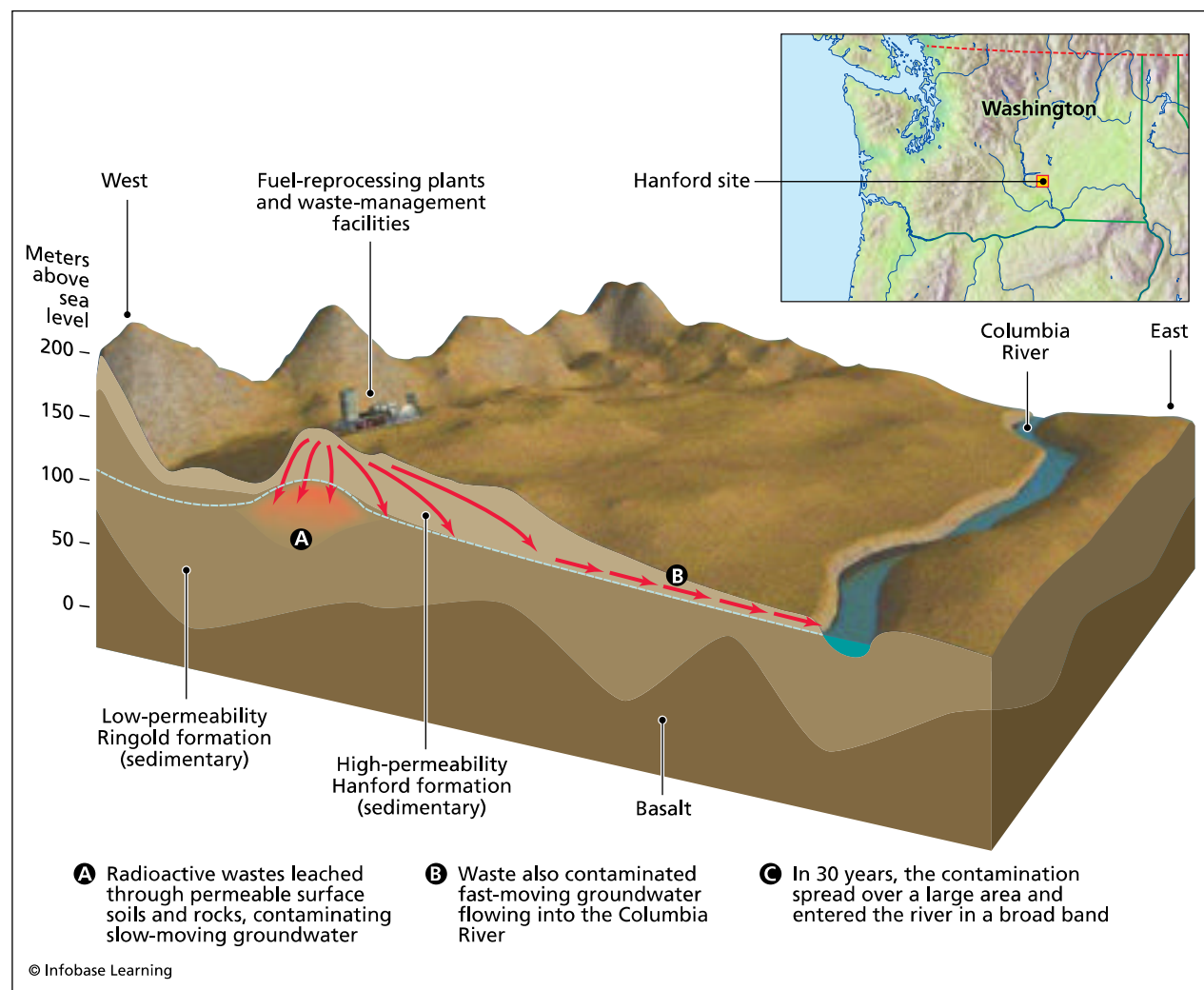
During fission, plutonium releases more heat and neutrons than U-235 and thus results in a much larger release of energy for a much smaller mass of fissionable material. For example, 2.2 pounds (1 kg)

of plutonium consumed (fission over three years) in a conventional nuclear reactor can produce enough heat to generate about 10 million kilowatt-hours of electricity. The sudden complete fission (detonation) of the same 2.2 pounds (1 kg) produces an explosion equal to about 20,000 tons (18,144 metric tons) of trinitrotoluene (TNT).

Plutonium was manufactured for weapons production in Hanford in special nuclear reactors. Uranium fuel rods were bombarded with neutrons, and once the maximal amount of plutonium was produced, workers removed the fuel rods (now called spent fuel) from the reactor. The spent fuel rods were extremely radioactive, and the process for recovering the plutonium used only remote-controlled equipment. The plutonium was recovered chemically by PUREX, a plutonium and uranium recovery process that employs extraction. The PUREX process was

used to remove uranium, plutonium, and other fission products from the spent fuel rods. The rods were dissolved in nitric acid with the liquid filtered to remove the insoluble solids (grit). An organic solvent composed of tributyl phosphate (TBP) and kerosene was used to precipitate uranium and plutonium, while the remaining fission products remained in the aqueous nitric phase. Once separated, further chemical processing divided the heavier plutonium from the uranium.

Efficient, reliable, but expensive (it is estimated that five pounds [11 kg]) of plutonium cost between \$10 million and \$40 million to manufacture), the plutonium production activities at Hanford required large quantities of water, both for cooling the reactors irradiating the uranium and for chemical processing. The presence of the Columbia River, which flows for a 50-mile (80.5-km) stretch along the



**Block diagram showing the radioactive pollution from the Hanford industrial site infiltrating the surface and flowing in the groundwater and into the Columbia River. The inset map shows the location of the Hanford site in the state of Washington.**



northern and eastern boundary of the Hanford site, was one of the main reasons why this area was chosen as the host site for plutonium production operations.

During the cold war, the Hanford Nuclear Reservation, the Hanford Project, the Hanford Works, or the Hanford Engineer Works, as the site was called at various times and under various conditions, expanded; eventually it included almost 400 miles (644 km) of paved roads, 160 miles (258 km) of railway lines, and four electrical substations. By the early 1960s, nine nuclear reactors were operating at the site along with five PUREX reprocessing plants, and the facility operated and maintained more than 900 support buildings and numerous radiological laboratories. After 43 years of operation, the last reactor was turned off in 1987 as the cold war slowly approached the end (1989 officially). During its life, Hanford had produced about 60 tons (54.4 metric tons) of plutonium.

### CLEANUP PLANS

The handling and processing of such hazardous materials left behind an environmental legacy that makes part of the Hanford Reservation one of the most contaminated places in the United States. Plutonium production ceased at Hanford in 1989, and the mission of the site changed from weapons production to environmental restoration. Despite almost 20 years of often-remarkable progress, the Hanford cleanup remains a daunting task. More than 40 million cubic yards (30.6 million m<sup>3</sup>) of radioactive waste was present on the site, along with almost 140 million cubic yards (107 million m<sup>3</sup>) of soil and debris contaminated with both radiological and hazardous constituents. Some 500 billion gallons (1,893 billion L) of process wastewater was discharged to the soil, and more than 80 square miles (200 km<sup>2</sup>) of groundwater has been contaminated with both radionuclides and industrial chemicals. The cleanup, which is being done by the U.S. Department of Energy (DOE) and its contractors under the oversight of the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology, has been organized as a Superfund site under the National Priorities List (NPL) to address the following four areas:

1. **100 Area:** This is a 26-square-mile (67.4-km) parcel along the Columbia River, where, between 1943 and 1963, nine water-cooled plutonium reactors were built and began to operate at six locations. The 100 Area reactors are being secured by

“cocooning.” This process involves demolishing supporting structures, then sealing and surrounding the reactor core and associated shielding by an aluminum- and zinc-coated building.

A major part of the cleanup of the 100 Area involves the K Basins. In these concrete-lined, water-filled vaults, more than 2,300 tons (2,087 metric tons) of spent nuclear fuel was stored. Only a few hundred yards from the Columbia River, the K Basins occasionally have leaked and, because of the deterioration of the spent fuel, now contain a layer of sludge. The spent fuel has been removed and is being reprocessed at another area of the site for eventual shipment to the Waste Isolation Pilot Plant (WIPP), but sludge removal is ongoing and it will be several more years before the K Basins are ready to be drained and decontaminated.

While in operation, the reactors discharged cooling water and disposed of solid wastes in more than 400 waste sites, including trenches, cribs (underground drain fields), ponds, and burial grounds. Leaks in the reactor’s wastewater piping and retention systems contaminated soil and groundwater. Remediation of soil involves excavation of more than 6 million tons (5.5 million metric tons) of contaminated soil and its redeposition in the Environmental Restoration Disposal Facility (ERDF), the secure, on-site landfill constructed at Hanford for the long-term management of its remediation wastes. Soil cleanup operations will be ongoing through at least 2012 and will include relocation and on-site disposal of 10 million tons (9.1 million metric tons) of materials. Pump-and-treat remediation as well as in situ treatment systems are being used to control migration and reduce levels of contaminants in the groundwater.

2. **200 Area:** This area is in the central portion of the Hanford site and covers about 15 square miles (39 km<sup>2</sup>). This area had no disposal locations for radioactive or mixed wastes, but hosts several sites where hazardous wastes including batteries and battery acid—containing lead, sulfuric acid, and ethylene glycol, or antifreeze, were discharged into the environment. In addition, historic discharges, primarily from the uranium processing plant, caused localized soil and groundwater contamination. More than 12,000 tons (10,900 metric tons) of waste was removed from an inactive landfill in this area and relocated to the ERDF. Cleanup of the 200 Area was completed in 1995; however, long-term groundwater treatment and monitoring are ongoing.



3. **300 Area:** This is a former 0.5-square-mile (1.3-km<sup>2</sup>) industrial area that contained a plant used for fabricating uranium reactor fuel as well as research facilities focused on improving plutonium production processes. Although some nuclear-related research continues in this area, the majority of the old laboratories have been deactivated, with the 220 buildings present there either demolished or scheduled for demolition. Liquid and solid wastes from operations in the 300 Area were disposed in unlined surface impoundments or landfills and contain low- to high-activity waste and transuranic (chemical elements with an atomic number greater than 92) contaminated materials. Approximately 840,000 tons (760,000 metric tons) of soil and debris has been removed from the 300 Area and disposed of at ERDF. Groundwater in this area will continue to be monitored to demonstrate that concentrations of solvents and radionuclides (trichloroethene, 1,2-dichloroethene, ammonia, arsenic, benzo(a)-pyrene, cadmium, chrysene, polychlorinated biphenyls [PCBs], thallium, tetrachloroethene, cesium 137, chloroform, copper, and nickel) present exceeding health-based concentration standards continue to decrease. Institutional controls also have been established to ensure that groundwater use is restricted to prevent unacceptable exposures to potential off-site users.
4. **1100 Area:** This area is in the southern portion of the Hanford Reservation and covers approximately five square miles (13 km<sup>2</sup>). It included the central warehousing, vehicle maintenance, and transportation distribution center for the entire Hanford Reservation, as well as a former NIKE missile base and control center for America's first anti-aircraft missile system. Wastes (solvents, paints, and acids) were disposed of in pits, on the ground, and in a landfill. Contaminated soil and waste residues were removed from this area and relocated to the ERDF. Cleanup was completed in 1995; however, long-term groundwater treatment and monitoring are ongoing.

There are numerous other areas at Hanford where remediation is ongoing, and certain locations such as the ERDF and cocooned reactors will never be completely restored to prefacility conditions. There also is a human component to Hanford operations. During manufacturing operations, both workers and nearby residents often were exposed to unacceptably high doses of radioactivity, which damaged their health and long-term quality of life. After

some prodding, DOE has recognized this important public health legacy and established compensation programs to help address those who have been adversely affected.

*See also* CHLORINATED SOLVENTS; IN SITU GROUNDWATER REMEDIATION; LANDFILL; LEAD; ORGANIC POLLUTANTS; RADIATION; RADIOACTIVE WASTE; SOIL POLLUTION; SUPERFUND SITES; WASTE ISOLATION PILOT PLANT; WATER POLLUTION.

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**Hawaiian Patriot oil spill** **Hawaii February 25, 1977** **Water Pollution** The archipelago of Hawaii was formed by geologic processes that resulted in the slow but massive release of thermal energy from deep within the Earth. Magma was generated from a mantle plume, or "hot spot," and flowed onto the seafloor, forming some of the tallest (submerged) mountains on Earth. The Pacific plate moved over this hot spot, first, forming the Emperor Seamounts, and, then, the Hawaiian Seamounts. About 5 million years ago, Kauai, the first of the Hawaiian Islands, fought its way to the surface. Next was Oahu, and later the islands of Molokai, Lanai, and Maui, all sharing the same volcanic base as Oahu. Finally, 500,000 years ago, the "Big Island" of Hawaii appeared. Today, there are seven active volcanoes on the island of Hawaii, and its main peak, Mauna Loa (elevation 16,684 feet [5,085.3 m] above sea level), would be one of the tallest mountains in the world, if measured from its true base some 30,000 feet (9,144 m) beneath the surface of the Pacific Ocean. The hot spot and plate tectonic movements continue, and 20 miles (32.2 km) to the southeast of Hawaii is an active volcanic area named Loihi where the next island will



Oil storage terminal and refinery, Oahu, Hawaii (tomas del amo/Alamy)

probably emerge, although not for at least another 10,000 years.

### BACKGROUND

Hawaii is one of the most energy-dependent places in the United States. Hawaii has no coal, oil, or natural gas deposits of its own and must import 90 percent of the fossil fuel needed to run its economy. These imports, mostly from Indonesia, are expensive, and Hawaiians pay some of the highest prices for gasoline and electricity in the United States. More than 30 percent of the petroleum Hawaii imports is used to make jet fuel, and the need for this and other refined petroleum products continues to grow.

Hawaii's population is currently 1.3 million and is expected to increase to 1.6 million by 2030. Oahu currently has a population density (1,650 people per square mile [644 per km<sup>2</sup>]) greater than that of New Jersey, the most densely populated state in the nation. Every day, Hawaii imports more than 140,000 barrels (22.3 million L) of oil and 24,000 barrels (3.8 million L) of refined petroleum products. To process these important energy sources, ports, storage terminals, and pipelines in two refineries on Oahu rival any major mainland facility in Houston

or Louisiana. It was toward one of these refineries that, in 1977, the tanker vessel, T/V, *Hawaiian Patriot* was bound.

### THE ACCIDENT AND OIL SPILL

Although not a supertanker, the *Hawaiian Patriot* was a large single-hulled ship, 846 feet (260 m) long with a carrying capacity of 30 million gallons (about 700,000 barrels, or 113.6 million L) of liquid petroleum. Fully loaded with a cargo of Indonesian crude oil, the ship was approximately 360 miles (579.4 km) west of Honolulu when one of the hull plates developed a crack. Oil began to leak into the waters of the northern Pacific Ocean, and a slick some 50 miles (80.5 km) long formed as it continued to steam toward Hawaii, the nearest harbor. On February 25, 1977, the crack worsened, one of the main hull plates of the *Hawaiian Patriot* apparently gave way, and approximately 5 million gallons (18.9 million L) of oil was released. As the thick, viscous fluid surrounded the vessel, smoke began pouring from one of the compartments amidships, and the ship suddenly exploded. The 39-man crew was forced to jump for their lives, and all but one were rescued by a passing merchant ship. Most of the surviving

seamen reported only minor injuries. The *Hawaiian Patriot* burned for a few more hours before eventually sinking, taking more than 25 million gallons (94.6 million L) of oil to the bottom of the Pacific Ocean. Although generally not recognized by most researchers, the loss of the *Hawaiian Patriot* was one of the largest oil spills at sea, equivalent to the *Torrey Canyon* disaster in 1967.

### THE ECONOMIC IMPACT

The environmental consequences of the *Hawaiian Patriot* disaster were never fully evaluated. The accident was so far from land that no impacts to Hawaiian beaches or shoreline habitats were observed. The surface slick was dispersed within a few days by natural degradation mechanisms, winds, waves, and evaporation, and no studies were conducted to assess potential impacts on ocean floor environments. There did not seem to be much of a short-term ecological impact from the sinking. The ship's insurers paid a claim for \$12 million, for the loss of the oil, and the crew and captain were reassigned to other vessels. The sinking of the *Hawaiian Patriot* was cited by the then president Jimmy Carter as one of the major reasons why oil tanker regulations, including upgrading of radar systems and more frequent safety inspections by the Coast Guard, needed to be toughened.

Although Hawaii still satisfies the majority of its energy needs by the importation of fossil fuels, steps are under way to make the islands more self-sufficient. Approximately 85 percent of Hawaii's electricity is generated through the burning of oil, and the remaining 15 percent is from such alternate energy sources as biomass from sugar plantations and municipal solid waste, hydroelectricity, wind, and geothermal sources. Plans are under way to increase the percentage of renewable energy electrical generation to 20 percent by the year 2020 through the use of such developing technologies as solar and ocean wave/current converters.

See also OIL SPILLS; TORREY CANYON OIL SPILL.

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**HCB (hexachlorobenzene)** HCB is a very dangerous substance because it is very persistent and tends to concentrate in animals and build its way up the food chain: It was banned for most agricultural uses in 1965, in part, because it was becoming prevalent in human breast milk. Further, the infants and small children affected were showing adverse health effects from this exposure. Before the ban, HCB was marketed under several names including Hexa CB, Phenyl perchloryl, Perchlorobenzene, Pentachlorophenyl chloride, Anticarie, Bunt-cure, Co-op hexa, Julin's carbon chloride, No bunt 40, No bunt 80, Sanocide, Snieciox, Smut-go, Granox nm, and Voronit C. Even though it is much less common than it was before the ban, it is still ranked the 93rd most dangerous chemical of 275 entries on the 2007 CERCLA Priority List of Hazardous Substances. It has been found in at least 107 of the 1,613 current or former U.S. Environmental Protection Agency (EPA)-designated Superfund sites where it was tested. It is the basic properties of HCB that make it such a danger to public health.

### PROPERTIES, USES, AND PRODUCTION

Hexachlorobenzene is an organic compound under the classification of chlorinated hydrocarbons that does not occur naturally. It typically exists as a white crystalline solid that may be needlelike in form. Commercial production of HCB began in 1933 in the United States but was greatly increased in 1945, when it became a popular fungicide for seeds. It was widely used on onions, sorghum, wheat, and other grains until 1965, when, as the result of adverse health effects, it was restricted and later banned for this use. It was also used to make electrodes, fireworks, ammunition, and synthetic rubber and as a chemical intermediate in the production of certain dyes and other organic chemicals.

HCB was purposefully produced in the United States until the late 1970s. In 1975, only 3,200 pounds (1,455 kg) of HCB was produced compared



with the millions of pounds of annual production prior to 1965. In 1972, 2.5 million–4.9 million pounds (1.1–2.23 million kg) of HCB was produced as an unwanted by-product during the production of chlorinated chemicals, but only 7,770–25,350 pounds (3,532–11,523 kg) was produced in 1984. It is also a by-product in the synthesis of several common chlorinated solvents and pesticides such as trichloroethylene (TCE), carbon tetrachloride, and others. In 1982, imports were reported to be 38,000 pounds (17,272 kg), and 58,000 pounds (26,364 kg) changed hands in 2000.

### ENVIRONMENTAL RELEASE AND FATE

HCB causes extensive damage when released to the environment but is most noted for its persistence. If it is released to the soil, HCB will adsorb strongly onto clay and organic particles and remain fixed. It will not leach into groundwater easily nor biodegrade appreciably. In one study, removal half-life of HCB was found to be 1,530 days (4.2 years), but it can vary between three to six years depending upon conditions. If it is released to surface waters such as lakes, rivers, and streams, that which remains at the surface will evaporate relatively quickly with a removal half-life of about eight hours. Most of the HCB, however, will strongly adsorb to the suspended particles in the water and settle to the bottom, becoming part of the sediment. This fraction will remain fixed for extended periods, with a removal half-life in the range of 2.7–5.7 years depending upon conditions. It will undergo minimal biodegradation. HCB may be released directly to groundwater, where it will undergo extremely slow breakdown with a half-life 5.3–11.4 years. If HCB is released to the air, it will exist primarily in the vapor phase or attach to particles. Breakdown as the result of chemical reaction with photochemically produced hydroxyl radicals has an estimated removal half-life ranging from 0.63 to 6.28 years (average two years) depending upon conditions. Otherwise, it may also be washed out of the atmosphere from precipitation events. As a result, HCB can travel long distances on a global scale and has been detected in glacial ice at the Poles.

HCB is very toxic to aquatic organisms and is a strong bioaccumulator. It accumulates in freshwater fish with log bioaccumulation factors of 3.7–4.3 for trout, 3.1–4.3 for sunfish, and 4.2–4.5 for minnows. Through this mechanism, HCB enters the food chain and can ultimately be ingested by humans.

According to the EPA's Toxic Chemical Release Inventory, in 1987–93, direct manufactured HCB releases to land and water had fallen to 1,287 pounds

(585 kg), all of which was to water and primarily in the states of Louisiana and Texas, though total releases (by-product to land, water, and air) between 1988 and 1999 ranged from 12,600 pounds (5,715 kg) to more than 1 million pounds (28,350 kg) per year. Since then, the EPA Toxic Release Inventory has listed a total release of 28,125 pounds (12,784 kg) in 1999 and 42,555 (19,343 kg) in 2005. These releases were primarily from the alkali, chlorine, and agricultural chemical industries to land and water. Estimates for release of HCB to the air ranged from 46,300 to 63,900 pounds (21,000 to 28,980 kg) per year in the past, but some estimates place the release of by-product HCB at 2–5 million pounds (0.9 million–2.3 million kg) per year.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from exposure to HCB, several of which are severe. Acute exposure to HCB produces skin lesions, muscle weakness, convulsions, and nerve and liver damage depending upon the level. High-level exposure can be fatal. Chronic long-term exposure to HCB can cause liver and kidney damage, problems with reproduction, and the development of tumors, especially on endocrine glands. HCB can also damage the thyroid and nervous system and, in laboratory animals, the bones and blood, and the immune and endocrine systems. There was a case in Turkey in which a large group of people ate grain for a long period that was accidentally contaminated by HCB. The result was that there was a high death rate in young children of mothers who ate the grain and in young children who ate it themselves. Infants who nursed from mothers who had eaten the grain were found to have elevated HCB from the transfer through breast milk. These infants suffered from a liver disease called porphyria cutanea tarda, the main effect of which is slowed or stopped formation of the oxygen-carrying part of hemoglobin in red blood cells. This disease can cause symptoms of red-colored urine, skin sores, change in skin color, arthritis, and problems of the liver, nervous system, and stomach. The skin sores are another disease, called pembe yara, or “pink sore.”

The U.S. Department of Health and Human Services classified HCB as reasonably anticipated to be a human carcinogen, and the International Agency for Research on Cancer (IARC) classified HCB as possibly carcinogenic to humans (group 2B). EPA determined that it is a probable human carcinogen. These classifications are based upon laboratory studies in which several animals had an increased incidence of liver, kidney, and possible thyroid tumors through exposure to HCB.



## REGULATIONS ON HUMAN EXPOSURE

There are several federal regulations governing public exposure to HCB. The EPA recently set a limit for HCB in drinking water at one part per billion (ppb) under the Safe Drinking Water Act. Prior to this, there were guidelines for drinking water that it not contain more than 0.05 part per million (ppm) in water that children drink and should not exceed 0.2 ppm in water that adults drink for longer periods (approximately seven years). They further require that a spill or leak of 10 pounds (4.5 kg) of HCB or more be reported to the National Response Center. The National Institute of Occupational Safety and Health (NIOSH) estimates that 4,400 workers were exposed to HCB from 1972 to 1974 but only 1,038 from 1981 to 1983 through their occupational health surveys.

See also ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; ORGANIC POLLUTANTS; PESTICIDES; SAFE DRINKING WATER ACT; SUPERFUND SITES.

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**HCB (hexachlorobutadiene)** If an environmental contaminant could be considered to fly below the radar, it would be HCB. It is a by-product and used as a chemical intermediate in the production of

chlorinated solvents, trichloroethylene (TCE), tetrachloroethylene (PCE), chlorofluorocarbons (CFCs), carbon tetrachloride, and other very dangerous environmental contaminants. It is, therefore, found together with these other chemicals and, as such, largely overlooked. The epidemiological studies and even the animal exposure studies are few and confounded by the presence of the other compounds. It has only been relatively recently that HCB has been identified as a possible danger. Yet it is ranked number 22 on the 2007 CERCLA Priority List of Hazardous Substances, which contains 275 entries. It is now regarded as more dangerous than many very dangerous substances. HCB is also known as Hexachloro-1,3-butadiene, Perchloro-1,3-butadiene, Perchlorobutadiene, Dolen-Pur, and GP-40-66:120. It has been identified in 45 of the first 1,350 EPA-designated Superfund sites (National Priorities List) for which it was tested.

## PROPERTIES, USES, AND PRODUCTION

HCB is a synthetically produced chlorinated alkene that is in the form of a clear, colorless, oily liquid with a turpentine odor. It is used as a solvent, heat transfer liquid (largely in transformers), hydraulic fluid, gyroscope fluid, and lubricant and in the manufacture of rubber compounds as well as those already listed. It was also used as a fumigant in other countries. It is estimated that between 7 million and 14.5 million pounds (3.3–6.6 million kg) was produced annually in the United States, but most of the HCB consumed domestically was imported from Germany. The world production of HCB was 22,000 tons (20,000 metric tons) in 1982.

## ENVIRONMENTAL RELEASE AND FATE

HCB is largely released to the environment by dumping, leaks, and spills at manufacturing, storage, and transfer facilities for both HCB and many volatile organic compounds (VOCs), and, therefore, it is primarily a point source pollutant. In 1997, the Toxics Release Inventory reported total production waste of HCB of 8.4 million pounds (3.8 million kg), and in 2006 it was 1,077 pounds (493 kg). It is released to the atmosphere by evaporation, smoke-stack emissions, and incineration. It is slowly broken down by photolysis and reaction with photochemically produced hydroxyl radicals. It can also attach to particulate and be dispersed in the atmosphere. Estimates for the atmospheric half-life for HCB range from 60 days to 2.3 years. In surface water, HCB is removed by slow evaporation from the surface or adsorption onto suspended particulate matter

and subsequent settling into the sediment, where it remains fixed. Evaporation is enhanced by water turbulence, but it is relatively slow. In soils, it adheres strongly to clay and organic matter and is relatively immobile in most soils. In sandy soils, however, it can be moderately mobile. HCBd can biodegrade under aerobic conditions, but there are no studies documenting the rate at which this occurs.

HCBd is moderately to highly toxic to aquatic life, especially crustaceans and fish. Studies have shown that HCBd can bioconcentrate in fish by factors of 5,800–17,000 ambient levels in certain species. Shellfish are also susceptible to bioaccumulation. There is no evidence, however, that it biomagnifies up the food chain. One study showed that in birds exposed to HCBd, decreased survival of chicks resulted, but there is very little information on this point.

### HEALTH EFFECTS FROM EXPOSURE

HCBd is considered to have moderate to high oral and inhalation toxicity, but there is no information for humans, just laboratory animals. Acute exposure may produce several adverse health effects including eye, nose, and skin irritation; difficulty in breathing; pulmonary irritation; damage to the kidneys and adrenal cortex; and death if the dose is high enough. Long-term, chronic exposure may produce damage to the kidneys and liver, anemia, weight loss, and increased mortality rate in many laboratory animals. It also causes retardation of fetal growth in pregnant animals and decreased birth weight. Rabbits also exhibited brain damage as a result of HCBd exposure. The International Agency on Cancer Research (IARC) has assigned HCBd to group 3, not classifiable as to its carcinogenicity to humans. The EPA has labeled it a possible human carcinogen. Results of studies of laboratory animals are equivocal but indicate a general enhanced risk of kidney cancer, benign lung and uterine tumors, and metastatic cancer of the lungs. In humans, an increase in mutations of blood cells was found. It was also found that HCBd causes genetic mutations and chromosomal aberrations in a variety of cells under laboratory conditions, a finding that supports the cancer evidence.

### REGULATIONS ON HUMAN EXPOSURE

The adverse health effects caused by exposure to HCBd have led federal agencies to regulate it. The EPA recommends limitations on exposure to HCBd in drinking water at 0.3 milligram per liter for periods up to 10 days and long-term exposure of 0.1

milligram per liter for children and 0.4 milligram per liter for adults. They further require that any spill or leak of one pound (0.45 kg) or more of HCBd be reported to the National Response Center. The Occupational Safety and Health Administration (OSHA) limits workplace air to a permissible exposure limit (PEL) of 0.02 part per million (ppm) HCBd for an eight-hour workday in a 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) sets the same amount for their recommended exposure limit (REL).

See also CHLORINATED SOLVENTS; ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NON-POINT SOURCE POLLUTION.

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**HCH (hexachlorocyclohexane)** There are eight isomers of the synthetic organochlorine HCH including alpha-, beta-, and delta-HCH. The most infamous of these is gamma-HCH, which is otherwise known as lindane, a very powerful insecticide. Lindane became famous because it concentrates in human breast milk. As the result of use in rice fields, levels as high as 6,500 parts per billion (ppb) of HCH were found in milk fat from China and Japan in the 1970s. Considering the current U.S. Environmental Protection Agency (EPA) drinking water standard is 0.2 ppb, these human milk contents are alarming and led to strong regulatory action, which has since greatly decreased those levels worldwide. Lindane has some trade and synonymous names including Agrocide, Ambrocide, Aparasin, Aphitiria, BoreKil,

Borer-Tox, Exagamma, Forlin, Gallogamma, Inexit, Isotox, Jacutin, Kwell, Lindafor, Lindagronox, Lindaterra, Lindatox, Lorexane, New Kotol, Noviagam, Quellada, Silvanol, Steward, Streunex, and Tri-6 and inappropriately as benzene hexachloride and its trade names Benesan, Benexane, and BHC. Even though lindane has not been produced in the United States since 1977 and has been highly restricted since 1983, it is still a persistent environmental threat, as are several of the other isomers. Of the first 1,662 EPA-designated Superfund sites (National Priority List), alpha-HCH was found in 146 sites, beta- in 159, gamma- in 189, and delta- in 126 sites of those for which it was tested. On the 2007 CERCLA Priority List of Hazardous Substances, gamma-HCH ranks number 32, beta-HCH ranks number 36, delta-HCH ranks number 43, alpha-HCH ranks number 115, and technical grade HCH ranks number 148 of the 275 worst pollutants.

### PRODUCTION AND USE

Lindane is a white or clear crystalline powder that is soluble in water and that may evaporate. It was first manufactured in the United States in 1945, and production peaked in the 1950s, when more than 15 million pounds (6.8 million kg) was produced. Even though it has not been produced in the United States since 1977, it is still imported in some compounds and formulated into others. In 2000, there were 18 suppliers in the United States. It has traditionally been used as an organochlorine insecticide and fumigant for soil-dwelling and plant-eating insects. It has been used about 95 percent for agricultural purposes including for rice and grain but also in warehouses, as seed treatment, and in control of insect-borne diseases. Currently, lindane is still used for treating seeds as well as preventing wood-inhabiting beetles; in flea dip for pets and livestock; for soil treatment; on fruit and nut trees, vegetables, timber, and ornamental plants; and for wood protection. It is also used for lotions, creams, and shampoos that help control lice and mites.

### ENVIRONMENTAL RELEASE AND FATE

As a commonly used insecticide, HCH was widely released as a nonpoint source pollutant from agricultural applications, as well as a point source pollutant from manufacturing and disposal sites. The most common pathway is in surface water from agricultural and residential runoff or industrial spills, dumping, and transfer and disposal leaks. Unless the surface water is highly agitated where the removal half-life is as short as 1.5 days, lindane does not

evaporate readily. Experiments show a removal half-life of 115–191 days for water deeper than three feet (1 m). It does not biodegrade or hydrolyze readily in surface water and photolysis is slow. It typically does not settle into sediment but may concentrate slightly by chemical diffusion. If released to soil, HCH will evaporate from the surface but not at depth. It will not undergo biodegradation under aerobic conditions (field half-life of 15 months) but appears to degrade rapidly under anaerobic conditions. In general, HCH in soil is mobile and leaches slowly and only partially into the groundwater system. Significant numbers of water wells in New Jersey, California, Mississippi, and South Carolina have been found to contain HCH. If released into the atmosphere, lindane will fall out directly, be washed out during precipitation events, or react with atmospheric hydroxyl radicals with a half-life of 1.63 days. It can remain in the atmosphere for up to 17 weeks. The standard monitored period from 1987 to 1993 for EPA's Toxic Release Inventory yielded only 1,115 pounds (506.8 kg) to both land and water because it had already been severely restricted. In 2006, only five pounds (2.2 kg) was reportedly released by industry.

In the natural environment, lindane is moderately toxic to birds at worst but tends to thin egg shells and result in reduced egg production. It is highly toxic to fish and invertebrate species and tends to bioaccumulate to 16–1,600 times the ambient level in mollusks, crustaceans, and some fish. It is also highly toxic to bees and virtually all insects and arachnids. Certain plants (carrots, for example) may preferentially absorb HCH.

### HEALTH EFFECTS FROM EXPOSURE

Exposure to HCH has been shown to cause numerous adverse health effects. Acute exposure to HCH by inhalation or ingestion results in stimulation of the central nervous system, mental and motor impairment, irritability, dizziness, headaches, changes in the levels of sex hormones in the blood, blood disorders (disruption of white blood cells), intermittent and continuous convulsions, pulmonary edema, respiratory failure, and death with increasing levels. It can also be a skin and eye irritant with dermal exposure and may produce some of the more serious reactions of intake exposure. Long-term chronic exposure to HCH has produced kidney, liver, pancreas, testes, ovary, and mucous membrane damage in laboratory animals and even convulsions and death. It was rapidly fatal to dogs in a two-year study. It also increased fetal mortality rate when pregnant animals were exposed. All HCH

isomers are designated as reasonably anticipated to be human carcinogens by the Department of Health and Human Services as the result of experiments on laboratory animals. The EPA has designated lindane (99 percent gamma-HCH) and alpha-HCH as probable human carcinogens. Experiments showed an increase in liver cancer for all rodents and potential increase in thyroid cancer in rats from lindane exposure. One study found that 100 percent of the mice exposed to alpha-HCH developed cancer. Several epidemiological studies of humans found a potential link between increases in lung cancer and leukemia and exposure to HCH.

### REGULATIONS ON HUMAN EXPOSURE

Federal regulatory agencies restrict the use and distribution of HCH. Lindane is listed as a restricted use pesticide by the EPA, which limits the concentration in groundwater to 0.2 ppb under the Safe Drinking Water Act. They further require that spills of lindane of one pound (0.45 kg) and spills of alpha-HCH of 10 pounds (4.5 kg) or more be reported to the National Response Center. Children should not be exposed to more than 1.2 milligrams of HCH per liter of water for more than 10 days. The Occupational Safety and Health Administration (OSHA) regulates workplace air to a permissible exposure limit (PEL) of 0.5 mg of lindane per cubic meter of air for an eight-hour workday in a 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) sets the same amount for their recommended exposure limit (REL) and an immediately dangerous to life and health (IDLH) limit of 50 mg of lindane per cubic meter of air. HCH is banned or severely restricted in more than 60 countries, and lindane is specifically banned or severely restricted in 46 countries.

*See also* ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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**heptachlor** Similar to chlordane in many aspects, heptachlor is an organochlorine cyclodiene insecticide that has been highly regulated for many years because of the health and environmental threats it poses. In fact, heptachlor was synthesized by isolating it from chlordane, and it was later banned in 1988 with chlordane, though heptachlor was originally restricted in 1978, about five years earlier than chlordane. Perhaps the most remarkable feature of heptachlor, however, is that a more dangerous contaminant, heptachlor epoxide, is produced by the natural chemical and biological transformation of heptachlor, not in a laboratory but in the environment. Heptachlor epoxide is subject to more stringent environmental regulations than its commercially produced parent. Trade names and synonyms for heptachlor include Aahepta, Agroceres, Hepta, Heptachlordane, Heptagran, Heptamul, Heptox, Gold Crest H-60, Rhodiachlor, Velsicol, Basaklor, Soleptax, and Termide, and even chlordane contains about 10 percent heptachlor. In the first 1,662 U.S. Environmental Protection Agency (EPA)-designated Superfund sites, heptachlor has been identified in 206 and heptachlor epoxide has been identified in 195; however, the number of sites tested for these compounds is not known. As a result of the severe adverse health effects from exposure, even with the ban, heptachlor still ranks number 34th on the 2007 Priority List of Hazardous Substances.

### PROPERTIES, USE, AND PRODUCTION

Heptachlor is a synthetic organic compound that was widely available as a dust, wettable powder, emulsifiable concentrate, and oil solution from its first formulation in 1946 (major distribution in 1953) until its domestic phaseout, which began in 1978 and was completed in 1988. It was used heavily during the 1960s and 1970s primarily by farmers



for the control of termites, ants, and soil insects such as cutworms, maggots, thrips, weevils, and wireworms on crops and in seeds. It was primarily used on corn, wheat, oats, barley, rye, sorghum, citrus, pineapple, and narcissus bulbs. It was also used by exterminators and homeowners to control termites. In pure form, heptachlor is a white or tan powder with a camphorlike odor. Most uses of heptachlor were banned in 1978. Since the second ban in 1988, the only permitted use of heptachlor is as a pesticide for fire ants in buried, pad-mounted electric transformers and in underground telephone boxes and cable television boxes in the southern United States. Heptachlor epoxide was used for a short time as a nonagricultural pesticide in small quantities. Production of heptachlor has varied through the years. In 1971, more than 5.95 million pounds (2.7 million kg) was produced by U.S. companies and primarily used domestically, whereas approximately 100,000 pounds (45,454 kg) was used in the United States in 1982 after the first restrictions were imposed. Production continued after the 1988 ban until 1994 but primarily for export. Export amount of heptachlor was 1.58 million pounds (718,181 kg) in 1992, 2.54 million pounds (1.15 million kg) in 1993, 1.24 million pounds (563,636 kg) in 1994, and 115,000 pounds (53,000 kg) in 1995, and 230,355 pounds (105,000 kg) of remaining stock after production ceased. Heptachlor remains stored in significant quantities in South Carolina, Tennessee, and Texas with lesser amounts in Florida and Ohio.

### ENVIRONMENTAL RELEASE AND FATE

Virtually all heptachlor was released to the environment as a nonpoint source pollutant through application as a pesticide and as a point source pollutant through accidental releases during production, transport, and storage or disposal. Most heptachlor applied to soil surfaces evaporated or underwent hydrolysis in moist soils. Once within the soil, heptachlor attaches itself to clays and organic material and remains fixed, resisting leaching into groundwater systems. It slowly biodegrades and/or oxidizes to 1-hydrochlordene, heptachlor epoxide, and other compounds. Sandy soils have the highest rate of degradation, which is up to 79.5 percent per year, in comparison to 5.25 percent per year for the slowest. Heptachlor epoxide also adheres to soil particles but strongly resists biodegradation and any other form of removal. It has been known to persist for 14–16 years in the upper layers of soil. In surface water, heptachlor evaporates, undergoes hydrolysis reactions to 1-hydrochlordene, or attaches itself to

particles and settles into the sediments. Biodegradation is under anaerobic conditions and slower in water but not as slow as in heptachlor epoxide, which also settles into the sediments and remains fixed. In air, heptachlor and heptachlor epoxide in the vapor phase react with hydroxyl radicals produced through photochemical reactions. Heptachlor epoxide attached to particulate matter and aerosols may travel for great distances before settling to the ground or being washed out by precipitation in even the most remote areas.

Heptachlor is moderately to highly toxic to birds. With heptachlor epoxide, it accumulates in body fat but has also been found in the liver, brain, muscle, and eggs. Heptachlor is highly toxic to bees. It is also highly toxic to fish and freshwater invertebrates such as snails, crayfish, and worms, in which it can bioaccumulate from 200 to 37,000 (average 5,000–15,000) times ambient levels. It is also taken up by plants and is subsequently accumulated in terrestrial animals as well. Human breast milk has been shown to have up to hundreds of times normal concentrations through this process.

### HEALTH EFFECTS FROM EXPOSURE

Heptachlor is classified as moderately to highly toxic through acute exposure by both ingestion and inhalation. Symptoms include hyperexcitation of the central nervous system, irritability, liver damage, loss of coordination, stomach distress, tremors, convulsions, coma, and, in severe cases, death by respiratory failure. Long-term, chronic exposure to heptachlor and heptachlor epoxide resulted in damage to the livers, kidneys, and red blood cells of laboratory animals. Humans specifically suffered blood dyscrasias and increased mortality rate from cerebrovascular disease through prolonged exposure. Increased cataracts have also been reported. They also produce adverse reproductive effects including decreased fertility, delayed development of offspring, and increased mortality rate. The EPA considers heptachlor and heptachlor epoxide to be group B2 probable human carcinogens. They produce an increased percentage of liver cancer in laboratory animals.

### REGULATIONS ON HUMAN EXPOSURE

Heptachlor was identified by Rachel Carson in her book *Silent Spring* as a dangerous pesticide, and the call was taken up by the fledgling American environmental movement. In part for this reason, heptachlor was one of the first pesticides to be regulated. The current EPA drinking water regulations under the Safe Drinking Water Act are 0.4 part per

billion (ppb) for heptachlor and 0.2 ppb for heptachlor epoxide, both of which are comparatively very low. The Occupational Safety and Health Administration (OSHA) limits the amount of heptachlor in workplace air to less than 0.5 milligram per cubic meter of air over an eight-hour workday, 40-hour workweek. Internationally, heptachlor and heptachlor epoxide are banned or restricted in more than 60 countries.

*See also* CARSON, RACHEL; ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**Hill Air Force Base Ogden, Utah 1987–present Soil and Water Pollution** In 1920, shortly after the end of World War I, in northern Utah, some 30 miles (48 km) north of Salt Lake City and about six miles (9.7 km) south of Ogden, the U.S. Army opened the Ogden Arsenal, a storage and maintenance operation for ammunition, artillery, and mechanized equipment. As World War II

approached, the base began to expand with the construction of four runways, and its operational mission started to shift from ammunition manufacturing and distribution to aircraft operations and maintenance. In 1955, operational responsibility for the base was transferred from the U.S. Army to the U.S. Air Force. Today, Hill Air Force Base (Hill AFB), named after Major Ployer P. Hill, a pilot killed during a test flight of a prototype B-17, is one of the U.S. Air Force's premier operational and mission support centers, occupying approximately 6,700 acres (2,711 ha) on the Weber River Delta, a sloping elevated alluvial terrace that lies about 300 feet (91.4 m) above the surrounding valleys. It is one of the largest employers in Utah with more than 23,000 employees, both civilian and military, and an annual payroll of more than \$800 million.

## CONTAMINATION OF THE SITE

Industrial processes taking place at Hill AFB include those typically associated with the refueling, repair, and maintenance of fighter aircraft, missiles, combat vehicles, and railroad engines. These include storage and dispensing of aviation fuels, metal plating, degreasing, paint stripping, and painting. Various types of chlorinated and nonchlorinated solvents and degreasers, petroleum hydrocarbons, acids, bases, and metals are used and generated as waste products by these operations. In the past, these chemicals and waste products were disposed of according to industry practices in effect at the time. That is, they were discharged to unlined disposal pits and sumps or simply buried in designated areas. By 1980, on-base disposal of hazardous materials had ended, and the air force was working closely with U.S. Environmental Protection Agency (EPA) and Utah's Department of Environmental Quality (UTDEQ) to address legacy soil and groundwater contamination, some of which dates back more than 80 years.

## THE CLEANUP

In July 1987, Hill AFB was placed on the National Priorities List (NPL) as an EPA-designated Superfund site. As such, areas where hazardous liquid and solid wastes generated by installation operations were disposed of could be addressed within this federally approved program. Nine Operable Units (OUs) have been identified at Hill AFB. OUs are waste disposal areas that can be grouped together by location, waste type, disposal method, or some other categorical basis. The status of each OU, in a different stage of investigation or remediation, is described in the following.

### OU-1

OU-1 is on the eastern side of the base and includes two landfills that were used for the disposal of liquid industrial waste and sanitary refuse between 1940 and 1974, two fire training areas where fuel was poured on the ground and ignited and extinguished as part of simulated aircraft fires, two chemical disposal pits where liquid industrial wastes were discharged between 1952 and 1973, a brick-lined waste phenol and oil pit where waste oil and phenols were burned for an 11-year period between 1954 and 1965, and four 20,000-gallon (75,708-L) above-ground tanks (removed in 1985) used for the storage of fuel oil, jet fuel, and hydraulic oil.

Contaminants found in the soil at OU-1 include volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, dioxins, furans, pesticides, and polychlorinated biphenyls (PCBs). The highest concentrations of contaminants were found near the fire training areas and the chemical disposal pits. A layer of light nonaqueous phase liquid (LNAPL) is floating on the water table in the area around the chemical disposal pits and the fire training area that is made up of jet fuel into which base neutral and acid extractable compounds have dissolved, along with dioxins and furans. In addition, PCBs also have been detected in the LNAPL near the chemical disposal pits. A plume of dissolved-phase contaminant constituents also is associated with OU-1 and is made up of dichloroethene (DCE), trichloroethylene (TCE), and arsenic. Fortunately, shallow groundwater is not used for potable purposes on or near Hill AFB.

### OU-2

OU-2 is located along the northern boundary of the base and includes two unlined trenches now covered by a building used in LNAPL recovery, where from 1967 to 1975 unknown quantities of TCE, sludge from solvent recovery units, and vapor degreasers were dumped. In the early 1940s, metal plating tank residues were emptied into these trenches. This area of the base is relatively isolated and infrequently used for military activities.

Soil within the operable unit contains a wide variety of organic and inorganic compounds including solvents, pesticides, and heavy metals. A layer of dense nonaqueous phase liquid (DNAPL) is present in the groundwater underlying the disposal trenches. The DNAPL layer consists primarily of a mixture of chlorinated and nonchlorinated solvents (trichloroethane [TCA], tetrachloroethylene [PCE], methylene chloride, toluene, and Freon) combined with some oil and grease. There are approximately 5,700 gallons

(21,577 L) of DNAPL present in the vadose zone and more than 100,000 gallons (378,540 L) of DNAPL below the water table in saturated sands and clays at the site.

### OU-3

OU-3 is in the southeastern part of the base and includes a vehicle refueling facility and two associated buildings, one for defueling/storage and the other used for a variety of purposes including engine repair and hydraulics and bearing maintenance, that were operated between the 1950s and 1985. Incidental spillage of fuel and solvents has resulted in soil contamination in this area consisting primarily of VOCs (1,1-DCE, PCE, and toluene); base, neutral, and acid extractable (BNAEs) compounds; pesticides (p,p'-DDT); PCBs; and metals. The highest contaminant concentrations are commonly within 10 feet (3 m) of the surface.

Also part of OU-3, are two 12,000-gallon (45,425-L) underground storage tanks that stored sodium hydroxide but were removed in 1992. An estimated 200,000 gallons (757,082 L) of solution was lost, apparently through an undetected leak, during the operation life of these tanks. This release of such large amounts of sodium hydroxide has raised the pH of nearby soil to levels greater than 8.5, which can have both public health and ecological impacts.

An unlined six-acre (2.4-ha) evaporation pond that received storm water and industrial wastewater containing spent solvents, heavy metals, and hydrocarbons is part of this OU. Now filled with construction rubble and capped, this pond was closed in 1986. Soil underlying the former evaporation pond is contaminated with VOCs, primarily benzene and chlorobenzene, BNAEs (dichlorobenzenes 1,2-DCB and 1,4-DCB), PCBs, metals, and cyanide.

No action is planned for the remaining two components of this OU: two small ponds and sludge drying beds that are part of the base's industrial wastewater treatment system. A risk assessment has concluded that the public health and ecological threats posed by the contaminants present at these facilities are below action levels.

### OU-4

OU-4 is a group of several waste management areas near the North Gate of the base. These include two municipal trash-type landfills that ceased operations in 1967 but might contain hazardous materials from prior facility operations, a spoils pit that holds soil and mixed construction debris, and two dump sites, one likely to contain liquid wastes discharged along

the North Gate access road and the other a munitions dump operated as an aboveground storage area during World War II. A plume of trichloroethylene (TCE) has been detected in the shallow groundwater in this area. Concentrations of TCE in this plume are above allowable drinking water quality standards. TCE also was detected in soil at this OU, but not at levels likely to cause adverse health effects.

#### **OU-5**

OU-5 is on the western side of Hill AFB and is made up of two areas, a rail shop and a series of buildings used for munitions and missile storage and rocket motor testing. Cleaning fluids and other chemicals including solvents, petroleum products, and sodium cyanide from railroad engine maintenance activities were discharged onto the ground in an undeveloped area west of the rail shop. Two contaminant plumes, both containing TCE, are present within the shallow groundwater at OU-5. Both are migrating off the base and toward homes in two local communities. Lead, total petroleum hydrocarbon (TPH), and arsenic were detected in on-base soils at this OU, but below levels that are expected to cause adverse health effects.

#### **OU-6**

OU-6 is on the northern side of Hill AFB and was designated after the discovery of groundwater contamination in a nearby residential subdivision. The source of this contamination is thought to be a fuel and waste sludge storage facility along with a suspected leach field. Soil contamination within this OU is not a significant issue, with DCE detected at or below levels that cause adverse health effects. Two contaminant plumes, however, are present in the shallow groundwater of this OU. Both are composed primarily of TCE that has been reported at concentrations exceeding drinking water standards.

#### **OU-7**

OU-7 is in the southeastern section of Hill AFB. It is a collection of areas in the industrial complex of the base and includes two buildings. One, used in electroplating, leaked chromic acid and PCBs into underlying soil. Underground storage tanks were present at the second building, and these tanks were used to collect paint stripping wastes. Apparently, the failure of pipes transferring the waste fluids to these tanks resulted in the discharge of solvents into underlying soil.

#### **OU-8**

OU-8 is in the southern area of Hill AFB. It was formed in 1993 and consolidates all groundwater

contamination present under the industrial complex of the base. It focuses on characterizing and remediating a plume of TCE present in the shallow groundwater.

#### **OU 9**

OU-9 is a catchall category, intended to include other sources of soil contamination that had not been previously identified. This includes areas in the vicinity of actively used buildings where a full investigation cannot be completed until sometime in the future. There are approximately 200 such sites in this category, and others are added if they contain significant contamination that is not already part of another OU.

#### **OU-10**

OU-10 consists of groundwater contamination of TCE at levels above drinking water standards and is present beneath three on-base buildings but also extends off-base toward two nearby communities.

#### **OU-11**

OU-11 is made up of soil and groundwater contamination at three on-base buildings and near the base golf course.

#### **OU-12**

OU-12 includes soil and groundwater contamination related to circa-1970 dumping of drums containing waste solvents and sludge in a two-acre (8,100 m<sup>2</sup>) area. Contaminants detected in the groundwater include TCE as well as carbon tetrachloride. These OUs are still under investigation, and a remedial solution has not yet been developed to address either the on-base or the off-base contamination.

In addition to the OUs listed, Hill AFB is responsible for the investigation and cleanup of several other areas. The Utah Test and Training Range in northwestern Utah and eastern Nevada is the location where Agent Orange herbicide testing and the disposal of ordnance, missile motors, and munitions residues from detonations and/or burns took place and, as a result, has contaminated surface soil. The Little Mountain Test Annex is north of Hill AFB near the Great Salt Lake. Sludge drying beds received industrial wastes from engine testing and missile hardness testing operations as well as phenolic paint strippers from Hill AFB and wastewater from adjacent water treatment plants. Wendover Air Force Auxiliary Field consists of a landfill and other maintenance facilities, and contamination is suspected as a result of solid waste, spent munitions, waste solvents, and suspected ordnance.



## RESULTS OF REMEDIATION

Hill AFB is working aggressively with the EPA and UTDEQ to address each of the OUs, and several have already achieved closure, or “No Further Action,” status. Hill AFB has constructed product interceptor trenches around source areas, installed LNAPL and DNAPL recovery systems to collect separate phase product, and built and operated soil vapor collection systems to help reduce the spread of solvents (especially TCE) on- and off-base.

For example, at one time, Hill AFB stored 100,000 gallons (378,540 L) of JP-4 jet fuel in four 25,000-gallon (94,635-L) underground tanks. Mixing kerosene with gasoline and naphthas makes jet fuels, also called turbine fuels. The result is an aviation fuel that has a high percentage of volatile hydrocarbons and burns much hotter and cleaner than gasoline or diesel fuels. The higher the number, the more kerosene there is in the fuel. JP-4 is the U.S. Air Force’s standard aviation fuel; JP-7 is high flash point special kerosene used in advanced supersonic aircraft. JP-5 is the navy’s standard aviation fuel. It has a lower flash point and volatility and is safer to store and use in the confined, below-deck spaces of aircraft carriers.

In 1989, these underground storage tanks were removed and replaced with aboveground storage vessels. During the tank replacement project, the air force found that JP-4 had been released into the soil. Moving quickly to delineate the extent of the release, the air force found that JP-4 had spread to include an area of soil about 30,000 square feet (2,788 m<sup>2</sup>) to a depth of 35–95 feet (10.7–29 m) below the surface. Depth to first groundwater in this part of the base is about 100–110 feet (30.5–33.5 m) below grade. The Hill AFB is an active facility, and the contamination extended beneath several mission-critical structures including an engine storage yard, fuel yard, and tool maintenance building. The air force decided to use an in situ biostimulation technology called bioventing to remediate the soil.

To grow and reproduce, bacteria need the right combination of moisture, air, nutrients, pH, and temperature. These are called limiting factors, because they control or limit bacterial growth. When a limiting factor is missing or deficient, growth stops and the bacterial population starts to decrease. Whereas it is difficult to change a soil’s pH or temperature, the management of other limiting factors such as moisture, nutrients, and air is more easily accomplished. The introduction or addition of nutrients, water, and sometimes air into soil to stimulate indigenous microbial populations needed to degrade organic pollutants is called biostimulation.

In bioventing, air is slowly injected into the subsurface through specially designed sparging wells.

This provides oxygen to microorganisms in the soil and stimulates bacterial degradation of petroleum hydrocarbon. Not to be confused with soil vapor extraction, which physically strips, or volatilizes, the contaminants, bioventing has the sole objective of providing enough oxygen to stimulate bacterial activity.

At Hill AFB, soil impacted by the JP-4 release had an average total petroleum hydrocarbons (TPH) concentration of almost 900 mg/kg, with some values greater than 5,000 mg/kg, which is close to saturation levels. For four years, beginning in 1991, the air force operated a bioventing system, consisting of one injection well and nine soil gas-monitoring wells. They regularly varied air injection rates to optimize system performance. Soil sampling after four years of system operation indicated that TPH levels had been significantly reduced within a 25-foot (7.6-m) radius of the injection well. TPH levels at the far edges of the plume did not drop, indicating that these areas had probably not been adequately aerated. The air force was so encouraged by these results that it quickly adopted bioventing as one of its major remedial techniques, installing similar systems at more than 140 sites around the country.

*See also* BENZENE; CARBON TETRACHLORIDE; CHLORINATED SOLVENTS; DCB; DCE; DDT; DIOXIN; IN SITU GROUNDWATER REMEDIATION; LANDFILL; LEAD; METHYLENE CHLORIDE; PAH; PCBs; PCE; TCA; TCE; TOLUENE; SUPERFUND SITES; UNDERGROUND STORAGE TANK; VOLATILE ORGANIC COMPOUND; WELLS.

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### **Hudson River PCB pollution Hudson Falls to Manhattan, New York, New York 1976–present Water and Sediment Pollution**

A capacitor, or condenser, is a passive electrical device that temporarily stores a charge. The simplest of capacitors are made up of two parallel metal plates separated or insulated from each other by a poor or slow-conducting substance called a dielectric. Dielectrics can be made from a variety of materials such as ceramics, glass, plastics, and even certain types of metals. Dry air is a very good dielectric, as are helium, nitrogen, and even distilled water. Commercial capacitors have the plates coiled together into tight, but separate, spirals and are placed inside a barrel-shaped container that has its interior filled by the dielectric.

Capacitors smooth out current fluctuations as an electrical device switches from one task to another. When connected, they are able to provide the extra energy needed to start a large industrial motor and are used in the circuit boards of all sorts of electronic apparatus, including audiovisual equipment, as filters, oscillators, power supplies, and amplifiers.

The key to the way a capacitor functions is the type of dielectric that separates its plates. It is this dielectric that determines, in large part, how much and how quickly the stored electrical charge can be discharged from the capacitor. For large industrial applications, dielectrics initially were wax or petroleum jelly, but trying to fill completely the barrel-shaped vessels that held the capacitors without leaving any voids

proved difficult. In the 1930s, a new type of dielectric was developed by Monsanto, Inc. It was a fluid with excellent stability at high temperatures, a high flash point, and resistance to moisture absorption. It quickly became the dielectric of choice for capacitors as well as electrical transformers. This new product was marketed under a variety of trade names such as Askarel, Aroclor, Pyroclor, and Pyranol, but it was simply a type of chlorinated heavy oil or hydrocarbon. Its common chemical name was polychlorinated biphenyls (PCBs). Available in more than 200 varieties, PCBs were not inexpensive but were widely used not only in electrical equipment but also in many other types of products such as coolants, lubricants, plasticizers, and adhesives.

### **BACKGROUND**

The General Electric Company (GE) quickly recognized the value of this new class of dielectric fluids. The company was founded in 1890 by Thomas Edison as the Edison General Electric Company to commercialize his newly invented incandescent light bulb. Edison merged with a competitor in 1892 and then moved the GE company to Schenectady, New York, to take advantage of the plentiful land and reliable electricity generated by the nearby Hudson River. Today GE is a multinational firm with 320,000 employees. It manufactures everything from jet engines to medical devices and provides a wide variety of commercial and retail financial services. Annual profit in 2006 was \$90 billion with approximately \$160 billion in total revenues. The company is headquartered in Connecticut but has



**General Electric Company capacitor plant in Hudson Falls, New York, 2000 (AP Images)**



**Map of the Hudson River in New York State showing key locations, including the General Electric operations in Hudson Falls and Fort Edward**

centered much of its eastern U.S. manufacturing activities within New York State, especially in the Albany area. In the late 1940s, two GE capacitor manufacturing facilities at Fort Edward and Hudson Falls began to use PCBs in the fabrication, repair, and refurbishing of capacitors and other electrical equipment. As manufacturing operations continued, these plants began to discharge PCB-laden wastewater into the Hudson River.

Originating in the Adirondack Mountains, the Hudson River's main channel is more than 315 miles (507 km) long and drains approximately 13,400 square miles (34,705 km<sup>2</sup>) before emptying into the Atlantic Ocean at the southern tip of Manhattan. The 150-mile (241.4-km) stretch of the Hudson between its confluence with the Mohawk River at Troy, New York, and upper New York harbor is an important commercial waterway. It connects the

New York State Canal system, most notably the Erie Canal, which originates some 400 miles (643.7 km) to the west near Buffalo, to the port of New York.

The river is informally divided into two sections: The Lower Hudson, which is actually a tidal estuary, is the section between the Battery in Manhattan (River Mile 0) and the Federal Dam near Troy at River Mile 153 (246 km). This dam, constructed across the river in 1916, was designed to improve access from the Hudson to the Erie Canal. The Upper Hudson is a 40-mile (64.4-km) stretch of the river between Hudson Falls and the Federal Dam at Troy that is separated into sections by eight smaller dams and locks. These dams provide navigational control for the Champlain Canal, which also is a part of the New York State barge canal system.

The Hudson River has played an important role in not only the economic achievements of the eastern United States, but also its cultural and literary development. In 1996, the U.S. Congress formally acknowledged the value of this important watershed and established the Hudson River Valley National Heritage Area. This is one of only 37 federally designated heritage areas funded and managed by the National Park Service. Its goal is to preserve, protect, and interpret the nationally significant cultural and natural resources of the Hudson River valley for the benefit of the nation.

### POLLUTION OF THE RIVER

The dams and locks on the Lower Hudson served an important role in navigation and commerce, but they also had an unintended environmental consequence. Throughout the postwar years and until 1977, GE's Fort Edward and Hudson Falls capacitor manufacturing facilities legally discharged wastewater containing PCBs into the Hudson River under permits issued by New York State. Although very stable and persistent in the environment, PCBs are not very soluble and are heavier than water. Once released, they tended to accumulate downstream not very far from the plants behind the dam at Fort Edward.

After more than 150 years of service, the dam's owner, Niagara-Mohawk Power, petitioned the Federal Power Commission (FPC), in 1973, for permission to remove the dam, because it had become unstable and could no longer be economically maintained. The FPC agreed, and between July and October of that year the dam was removed. As the reservoir that had been created by the dam drained, and the river channel reestablished itself, the PCB-laden sediments that had collected in the reservoir behind the dam were exposed. These contaminated sediments were concentrated in a 1.5-mile (2.4-km) stretch of the Hudson River, just upstream of the former dam. Spring 1974,



however, was unusually wet, and the Hudson River south of Fort Edward experienced several 10-year flood events, which flushed the PCB-bearing sediments farther downstream. Subsequent flooding and the natural tidal movements of the Hudson River eventually spread the PCBs along its entire length.

PCB discharges from the two GE capacitor plants continued until 1977, and studies by the New York State Department of Environmental Conservation (NYSDEC), the U.S. Environmental Protection Agency (EPA), and GE have estimated that about 1 million pounds (453,592 kg) of PCBs was released into the Hudson River system south of Fort Edward over the 30 years between 1947 and 1977. Although much of the material has been either removed (dredged) by GE or washed out to sea, estimates by the EPA still place the total amount of PCBs remaining in Hudson River sediments at 500,000–660,000 pounds (226,796–299,371 kg).

By the 1970s, public health and environmental officials had become concerned about possible physiological impacts from exposure to PCBs, and there was a growing body of evidence to indicate that PCBs were bioaccumulating and biomagnifying in the environment. The United States and Canada banned the production of PCBs in 1976 and instituted rules for their gradual phaseout and replacement. Most other countries passed similar bans shortly thereafter. Studies have linked PCBs to liver and nerve damage, and there is credible evidence that they may be carcinogenic and cause fetal injury.

In 1976, NYSDEC banned commercial fishing for most of the Hudson River's main species, including striped bass, carp, and perch. Sports fishing was still allowed, but anglers were advised to take a "catch and release" approach and not to eat fish from the river. The New York State Department of Health (NYSDOH) issued an advisory that warned women of childbearing age and children younger than age 15 not to eat fish from the Hudson River south of Hudson Falls. This same advisory recommends that no one should eat any fish caught between Hudson Falls and the Federal Dam in Troy. A 2001 advisory reduced some of these restrictions but still recommends limits on consumption of fish caught in the river. For striped bass, the advisory suggests no more than one meal per month if the fish was caught in the Lower Hudson south of the Tappan Zee Bridge. No striped bass should be eaten if caught in the Upper Hudson.

### THE CLEANUP

In 1984, the Upper Hudson River site, a 43-mile (69.2-km) stretch from the Fennimore Bridge in Hudson Falls (river mile 197 [317 km]) to Federal Dam at Troy (river mile 154 [246 km]) was added

to the National Priorities List (NPL) as a Superfund site. This listing was later expanded to include the Lower Hudson River Site from Troy to the Battery in Manhattan, a distance of about 200 miles (320 km), making the combined Hudson River Site one of the largest Superfund projects in the United States. As part of the NPL process, the USEPA notified GE that the company would be responsible for implementing the measures needed to address the presence of PCB-contaminated sediments in the river.

In September 1984, the USEPA issued a Record of Decision that stated: "A technologically feasible, cost-effective remedial response to PCB contamination in the riverbed that would be reliable and would effectively mitigate and minimize damage to public health, welfare and the environment is not presently available." In other words, any attempt to remove the PCB-contaminated river sediments would cause more harm than good. Although NYSDEC did not agree with this finding, the USEPA concluded that the PCB-laden sediments were being covered over or naturally encapsulated and that, given time, they would become isolated from the environment and no longer pose a significant ecological or public health threat. In the meantime, NYSDEC and GE implemented a series of remedial actions designed to reduce or prevent further migration of PCBs into the Hudson River from its two capacitor plants.

In the mid-1970s, NYSDEC directed the removal of more than 770,000 cubic yards (588,707 m<sup>3</sup>) of PCB-contaminated sediment and related debris from the navigational channel of the Champlain Canal near Fort Edward. These materials were placed in specially constructed spoil pits and buried beneath a low-permeability cover. Throughout mid-1990 and most of 1991, GE capped in situ 50–60 acres (20.2–24.3 ha) of remnant PCB deposits exposed on the banks and shoreline of the Hudson River after the Fort Edward dam had been removed and its reservoir drained.

From late 1997 through September 1998, GE removed 1,100 cubic yards (8,410 m<sup>3</sup>) of debris and sediment containing PCBs from an area near its Fort Edward plant to allow inspection of the underlying bedrock for the presence of PCB seepage. In 1994 and 1995, GE also excavated, from a series of tunnels underneath its Fort Edward plant, 3,400 tons (3,084 metric tons) of sediment that contained approximately 45 tons (40.8 metric tons) of PCBs. As part of this work, breaks and fractures in the bedrock of these tunnels where PCBs were leaking out were grouted and a groundwater collection system was installed to capture PCB-contaminated groundwater that was leaking from underneath the Hudson Falls plant and into the river. By mid-2001, more than 3,000 gallons (11,356 L) of PCB-contaminated water



had been recovered and shipped off-site for disposal. More than 230 groundwater recovery and monitoring wells have been installed to create a hydraulic barrier between the Hudson Falls site and the river. These wells serve to collect both separate-phase PCB liquids and PCB-contaminated groundwater. After treatment, collected groundwater is discharged back into the Hudson River.

As a result of these and other remedial activities mandated by the EPA and carried out by GE, PCB levels in the Hudson River ecosystem have been declining. The highest reported PCB concentrations in Hudson River sediments occurred in the early 1970s; they were due, in large part, to the continuing releases of PCBs and PCB-laden wastewater from the capacitor plants and the Fort Edward dam removal. Average PCB concentrations in sediments near Fort Edward were greater than 50 parts per million (ppm) in 1977 but were reduced to about 10 ppm in 1998. Similarly, PCB concentrations in fish from the Upper Hudson River have declined from about 80 ppm in largemouth bass in the 1970s to about 4 ppm in 1997. The Food and Drug Administration has established a safe tolerance level for PCBs in fish of 2 ppm.

Despite these and other indications of ecological improvement, the EPA and NYSDEC issued a new Record of Decision in 2002 calling for the removal of all PCB-contaminated sediment in the Upper Hudson River with a concentration greater than three grams per square meter. This translates to a total volume of sediments equal to about 1.56 million cubic yards (1,192,706 m<sup>3</sup>). Another 0.6 million cubic yards (458,733 m<sup>3</sup>) of sediment with a PCB concentration greater than 10 grams per square meter is to be removed from a separate stretch of the river. Approximately 0.5 million cubic yards (382,277 m<sup>3</sup>) of PCB removal will also take place from designated “hot spots” of elevated levels. This massive dredging project is to be closely monitored for possible air quality impacts, noise, disruption to river traffic, and resuspension of now-buried PCBs into the ecosystem. Contaminated dredge spoils are dewatered and stabilized at a special nearby processing facility and shipped to a designated disposal site in Texas. The cost of this work, to be paid for by GE, is estimated at around \$500 million.

The decision to implement such a massive dredging program is controversial, and many scientists and researchers doubt that it is necessary or appropriate. They doubt that it will provide much of a public health or ecological benefit. These concerns are based on questions as to whether PCBs are really as harmful as some of the toxicological data indicate. Health effects observed in laboratory animal

studies are difficult to extrapolate to humans. There is a body of evidence that indicates that people must be exposed to much higher levels of PCBs than is present in Hudson River sediments for them to be damaging. Other studies have found that PCBs, once absorbed onto the sediments, may not be leaching or may leach only very slowly into river water and may not be acting as a continuing source of contamination. Finally, some researchers have developed models showing that the chance of large-scale remobilization of PCBs from sediment into the river is low, even in extreme weather events. The money that will be spent to remove the contaminated sediments would be more beneficial to public health and ecological impacts if directed to other environmental needs, such as controlling urban runoff. Research into these and other areas continues, and future findings will no doubt play a role in the final implementation of the dredging program, which began in 2009.

See also BIOACCUMULATION AND BIOMAGNIFICATION; PCBs; STREAMS; SUPERFUND SITES; TIDES; WELLS.

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**Hurricane Katrina New Orleans, Louisiana August 23–31, 2005** *Water Pollution* The most costly natural disaster in the history of the United States was spawned in August 2005 in the Atlantic Ocean. Hurricane Katrina strengthened from a tropical depression and tropical storm on August 23 just before it made landfall in South Florida as a

category 1 hurricane. Once it crossed over into the warm waters of the Gulf of Mexico and strengthened quickly to category 5 status on the morning of August 28, it reached its peak strength that day, with maximal sustained winds of 175 miles (280 km) per hour. Katrina swung from its westward track to a northward track heading just east of New Orleans, Louisiana. This was the killer track that residents of New Orleans had been warned about for several decades.

### LANDFALL AND DAMAGE

The powerful left side of the storm pushed a huge storm surge northward onto the Gulf Coast of Mississippi, causing extensive damage there. The leading edge of the storm swept this swelled Gulf of Mexico water westward through the Rigolets, a narrow opening in a thin strip of land, and into Lake Ponchartrain, Louisiana. This huge lake is 35 miles (56 km) long by 25 miles (40 km) wide and lies immediately north of the city of New Orleans. There are a series of earthen levees along the south shore

of the lake to protect the city from storms on the lake. Hurricane Katrina passed just to the east of the lake still at category 3 strength. The full force of the weaker left-side winds heading due south created a storm surge on the now-overfilled lake that swamped the levees and sent a wall of water hurtling southward through the city. This storm surge caused 53 different levee breaches in greater New Orleans and submerged 80 percent of the city.

The damage totals were staggering. At least 1,836 people lost their lives directly in Hurricane Katrina or in the subsequent floods, making it one of the deadliest hurricanes in U.S. history. The storm is estimated to have been responsible for upward of \$81.2 billion in damage, making it, by far, the costliest natural disaster in U.S. history. The city of New Orleans would still not have recovered from the destruction four years later in spite of extensive rebuilding efforts. There was even a sizable faction in favor of abandoning the city forever.

### ENVIRONMENTAL DAMAGE

The city of New Orleans was literally submerged after Katrina passed through. As part of the cleanup effort, the brackish floodwaters were pumped into Lake Pontchartrain by using powerful pumps that operated around the clock. Completing this process took 43 days. When they struck the city, these floodwaters inundated the sewage system and raw sewage spilled out at numerous locations. They inundated numerous homes and businesses and even landfills and cemeteries, leaching an enormous amount of hazardous substances that threatened public health. The residual floodwaters contained a mix of raw sewage, bacteria, heavy metals, pesticides, toxic chemicals, and crude and refined oil, all fermenting together in the hot Louisiana sun. This “toxic soup,” as some called it, was cleaned up by many groups including the military over the next year or more. Great care had to be exercised in handling this waste mainly because of the potential for disease.

The extensive petroleum and petrochemical industry in Louisiana is a great boon to the economy but a great danger during a disaster like the hurricane of 2005. As a result of Hurricane Katrina there were 25 spills of 50 barrels (2,100 gallons [7,980 L]) or more, all of which required remediation, and another 18 spills of this size less than one month later when Hurricane Rita also struck Louisiana. The Department of Homeland Security estimates that the two together totaled six major, five medium, and more than 5,000 minor oil and hazardous material responses at the outset. Additional minor spills continued to be identified and addressed for the



**Map of the path and intensity of Hurricane Katrina from the Atlantic Ocean across Florida, into the Gulf of Mexico, and making final landfall in Louisiana and Alabama**

## Hurricane Floyd and Hog Waste in Eastern North Carolina

North Carolina has developed a booming hog farming industry. It grew from 2 million hogs in 1990 to 10 million hogs by 1997, making it the second largest hog producer in the United States. The rapid growth in the 1990s was facilitated by the building of large automated confining farms that housed hundreds to thousands of hogs. The hog farmers formed a politically strong group and were allowed to expand their farms and facilities without restriction. Many of the factorylike farms were built on the floodplains of sizable rivers and in reclaimed wetlands that are environmentally sensitive and prone to flooding. The problem is that each hog produces approximately two tons (1.8 metric tons) of waste per year, and the total yearly output for the entire area was on the order of 20 million tons (18 million metric tons) of waste. Disposal of the waste became a serious issue because there was so much of it and so much of a risk to public health. The solution adopted by the farmers was to build huge unlined lagoons into which they pumped both the liquid and the solid waste. The lagoons were the size of football fields (300 feet [92 m] by 150 feet [46 m]) and filled 10–15 feet (3–5 m) deep in waste.

Environmentalists warned that this situation was a disaster waiting to happen. In this area of North Carolina, heavy rains are common, and it is hurricane prone. There were even a few collapses of lagoons

that sent tons of rotting waste into rivers and through towns, causing not only health hazards but also vile odors, the likes of which are unimaginable. The situation was widely publicized and even appeared on the television show *60 Minutes*. The pressure grew so great that finally, in 1997, a law was enacted to prohibit the building of new waste lagoons on floodplains, and in 1999 the governor of North Carolina proposed a 10-year plan to introduce new technology for waste treatment and to phase out the then-4,000 waste lagoons.

### THE POLLUTION

The problem was that nature did not wait until the cleanup could take place. In late August 1999, Hurricane Dennis struck North Carolina and filled lakes, rivers, and reservoirs to capacity and completely saturated the ground with water. Just two weeks later, the larger and more powerful Hurricane Floyd struck the same area. It produced 20 inches (50 cm) of rain in eastern North Carolina, killed nearly 50 people, forced 48,000 people into shelters, and destroyed 2.3 million acres (931,000 ha) of crops. The environmental disaster resulted from the hog farming industry. Some 38 waste lagoons completely washed out, and 250 operations were flooded or had overflowing lagoons. It is estimated that 250 million gallons (946 million L) of untreated pig waste was dumped into riv-

next year or more. They estimated that more than 9 million gallons (34.2 million L) of oil was released during the major spills alone.

These major spills required extensive treatment and repairs and contributed the largest volume to the pollution problems in the area.

### **Murphy Oil Corporation Refinery: Chalmette, Louisiana**

It is estimated that more than 819,000 gallons (3.1 million L) of oil was discharged during the storm. The vast majority of the oil had been contained within the existing secondary containment unit located on refinery property. Murphy Oil launched an aggressive cleanup effort, and approximately 83 percent of the oil from the spill either had been recovered or had evaporated within one year. Hundreds of homes adjacent to the facility were saturated with oil during the leak. Many of the homeowners accepted a settlement from Murphy Oil, but others initiated a class action lawsuit against them.

### **Shell Pipeline Company: Pilot Town and Port Sulphur, Louisiana**

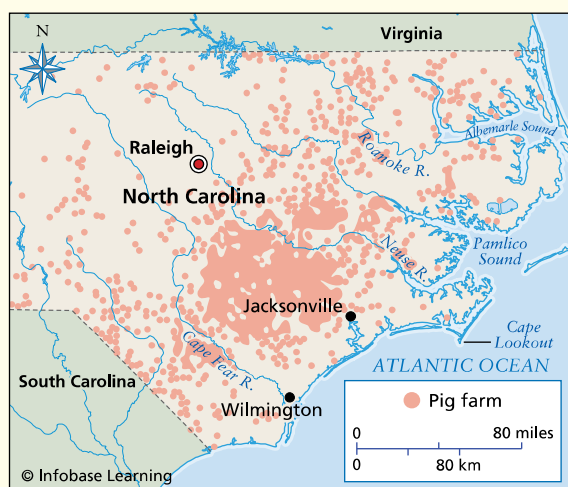
In Pilot Town, crude oil leaked from an above-ground storage tank and into a tank dike and the surrounding area. More than 1.1 million gallons (4.2 million L) was estimated to have leaked, but more than 849,030 gallons (3.2 million L) of it was recovered within one year. In Nairn, Louisiana, some 136,290 gallons (517,900 L) of crude oil leaked from a 20-inch (50-cm) pipeline. Damage to the pipeline resulted from a breach in a hurricane protection levee.

### **Bass Enterprises Production Company: Pointe a la Hache, Louisiana**

Approximately 461,538 gallons (1.75 million L) of oil leaked from storage tanks into the secondary containment system surrounding the tanks during and after Hurricane Rita. Within one year, some 30,660 gallons (116,508 L) had been recovered and approximately 225,330 gallons (856,254 L) was naturally dispersed or evaporated.

ers, creeks, and wetlands. In addition, approximately 30,000 hogs perished along with 2 million chickens and 735,000 turkeys.

Most of the poultry was simply piled up and left to rot. The state sent out mobile incinerators to destroy the decaying hog carcasses, but there were too many and farmers were instructed to bury as many as possible in pits. These pits were supposed to be on dry ground and at least 3.3 feet (1 m) deep, but there was very little dry ground at the time and no oversight on the operations. As a result of the



**Map of eastern North Carolina showing the distribution of hog farms in 2000**

flooded waste and the rotting carcasses, the surface water and groundwater in the area became a mass of bacteria and disease and remained so for months. Residents had to use bottled water or risk disease or even death. The stench that accompanied this disaster has been described as unbearable.

### THE AFTERMATH

Largely as a result of the Hurricane Floyd contamination, in July 2007, North Carolina became the first state in the nation to ban the construction or expansion of waste lagoons and spray fields on hog farms. This ban is part of the legislation in the Swine Farm Environmental Performance Standards Act. The ban is designed to prevent these contamination problems in the event of another hurricane or severe storm.

*See also E. COLI; HURRICANES AND POLLUTION; STREAMS; WATER POLLUTION.*

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—by Alexander E. Gates

### **Bass Enterprises Production Company: Cox Bay, Louisiana**

As a result of damage from Hurricane Rita, approximately 3.7 million gallons (14 million L) of oil was released. Within one year, 1.1 million gallons (4.2 million L) had been recovered, and approximately 982,800 gallons (3.7 million L) was naturally dispersed or evaporated.

### **Chevron Empire Terminal and Pipeline: Buras and Port Sulphur, Louisiana**

A significant but unreported amount of oil that was discharged from a storage tank at the terminal at Buras as a result of Hurricane Katrina was naturally dispersed and evaporated. Oil recovery operations and debris cleanup were under way at the time Hurricane Rita struck and had to be suspended, and emergency response personnel had to be evacuated. That is why estimates are uncertain. The pipeline rupture at Port Sulphur spilled approximately 1.4 million gallons (5.3 million L)

of oil, the cleanup of which was also hampered by Hurricane Rita.

### **Sundown West: Potash, Louisiana**

An estimated 13,440 gallons (51,072 L) of oil was discharged from tanks and piping that were ruptured during the storm. Within one year, approximately 7,686 gallons (29,207 L) of the oil was recovered and treated.

### **Sundown East: Potash, Louisiana**

An estimated 18,900 gallons (71,820) of oil was discharged from tanks and piping that were ruptured during the storm. Within one year, approximately 8,400 gallons (31,920 L) had been recovered.

### **Dynegy Venice: Venice, Louisiana**

Dynegy Midstream Services operates the Venice Energy Services Company (VESCO), a natural gas processing facility in Venice, Louisiana. They undertook the cleanup of environmental damage



associated with Hurricane Katrina. Approximately 24,822 gallons (94,324 L) was discharged as a result of storm damage. Within one year, 16,002 gallons (61,000 L) had been recovered and the remaining 8,820 gallons (33,516 L) was contained in a diked and boomed area.

See also HURRICANES AND POLLUTION; INORGANIC POLLUTANTS; OIL SPILLS.

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**hurricanes and pollution** When a hurricane that has strengthened over the ocean finally makes landfall (goes ashore), the media cover the accompanying death and destruction as headline stories for as long as there is public interest. Considering the devastating effects of a hurricane on a community and its population, the media attention is appropriate and necessary. In comparison, everything else about the storm is understandably incidental. One of the main incidental aspects of a hurricane is the environmental damage that it does to the community. The effects can be both natural and a result of the destruction of structures. Although potentially severe, these environmental effects are typically reported in less detail than the primary effects of the hurricane. Instead, they are relegated to secondary reports, if reported at all. These environmental effects, however, can be devastating to an area and take several years from which to recover. Indeed, in some cases, they can be more damaging to the community than the primary effects of the hurricane itself.

#### DEVELOPMENT OF HURRICANES

Hurricanes are tropical storms that are considered to be the most powerful meteorological events on Earth. A fully developed hurricane produces and consumes enough energy per day to power the entire United States energy needs for an entire year. These huge storms are only called hurricanes if they occur

in the Atlantic Ocean or adjacent related waters such as the Caribbean Sea and Gulf of Mexico. They are called typhoons in the Pacific Ocean and cyclones in the Indian Ocean. All are produced in the same way and are equally powerful.

Unlike most weather disturbances, such as tornadoes or blizzards, hurricanes are not associated with major weather-producing systems such as fronts or large low-pressure systems. They are not associated with permanent weather-driving features such as the jet stream. Instead, they most commonly begin inconspicuously as a modest cluster of thunderstorms in the Atlantic Ocean, off the west coast of Africa. Rather than being associated with a front or deep low-pressure system, as would be expected for large storms, hurricanes can only develop within large stable air masses with little wind. They can also only develop if the surface ocean water temperature is 79°F (25°C) or greater. At this temperature, the humidity is high in the air above the water surface. This humid air is swept up into the updrafts of the thunderstorms. As it rises, the moisture condenses to form rain, and at this vapor-to-liquid phase, there is latent heat transfer into the storm. This energy added to the storm causes pressure to decrease and the updraft to increase. The winds sweeping into the storm whip up the surface of the ocean water into waves that in turn expose more water surface from which more humidity can be formed. More humidity leads to more condensation and more latent heat transfer in a positive feedback system that powers up the storm.

The growing storm rotates counterclockwise in the Northern Hemisphere as the result of the Coriolis force, which is driven by the rotation of the Earth. In the Southern Hemisphere, tropical storms rotate clockwise. As the result of the momentum of these massive spinning systems, they cannot cross the equator. As the spinning storm grows, it develops a clear spot at its center called the eye of the hurricane that ranges from 20 to 40 miles (32–64 km) in diameter. The eyewall that surrounds the eye is the most dangerous part of the storm, containing the strongest winds and heaviest rains. Outward from the eyewall there are spiral rain bands of five to 10 miles (8–16 km) width and several hundred miles in length. These rain bands define the entire outer part of the hurricane. Hurricanes are typically about 300 miles (480 km) wide but range from 200 to more than 500 miles (320 to 800 km). There is significant wind in the areas between the bands but little to no rain. The location of the heavy clouds and rain in a hurricane shows where the air is rising and thus the lower pressure. Where there is no rain, the air is falling and thus the pressure is higher.

Hurricanes are not tied to major weather systems and fronts and are therefore unguided. This is why it is very difficult to determine the direction and speed that a hurricane will travel and why they can follow such illogical paths. They typically travel at about 15–20 miles (24–32 km) per hour but can achieve speed of 60 miles (96 km) per hour in some instances. In reality, hurricanes are very fragile storms. If they make landfall, travel over ocean with surface temperatures below 79°F (85°C), or encounter a front with high-level winds or another basic weather feature, they will quickly degrade.

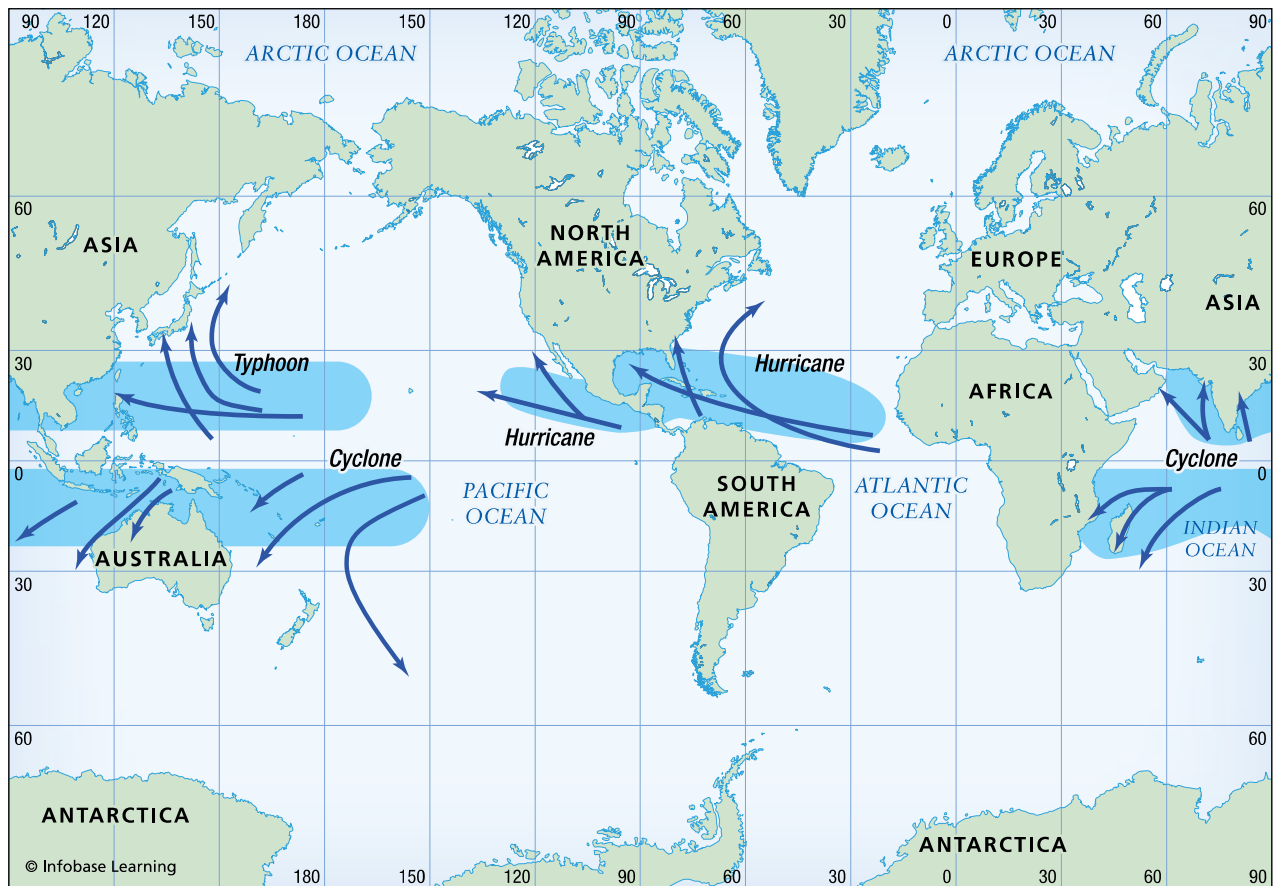
### CLASSIFICATION OF HURRICANES

There are several classification systems for tropical disturbances. The general system divides them into tropical depression, tropical storm, and hurricane classifications. A tropical depression is an organized system of thunderstorms with a defined surface circulation and maximal sustained winds of 38 miles per hour (61 km/h). A tropical storm is an organized system of strong thunderstorms with

surface circulation and maximal sustained winds of 39–73 miles (62–117 km) per hour. A hurricane is an intense tropical weather system of strong thunderstorms with well-defined circulation and maximal sustained winds of 74 miles (118 km) per hour or higher.

The standard system for classifying hurricanes is based on the Saffir-Simpson damage potential scale. This scale is primarily determined by news reports based on the maximal sustained winds but in reality has several factors that are supposed to be evaluated. These factors include the height of the storm surge waves, the inland flooding of ocean water, and the damage done to homes and other structures. The following are five categories of hurricanes in this Saffir-Simpson scale:

- **Category 1:** hurricanes that have sustained winds of 74–95 miles per hour (119–153 km/h). These storms produce damage to unanchored mobile homes, shrubbery, and trees but no real damage to building structures.

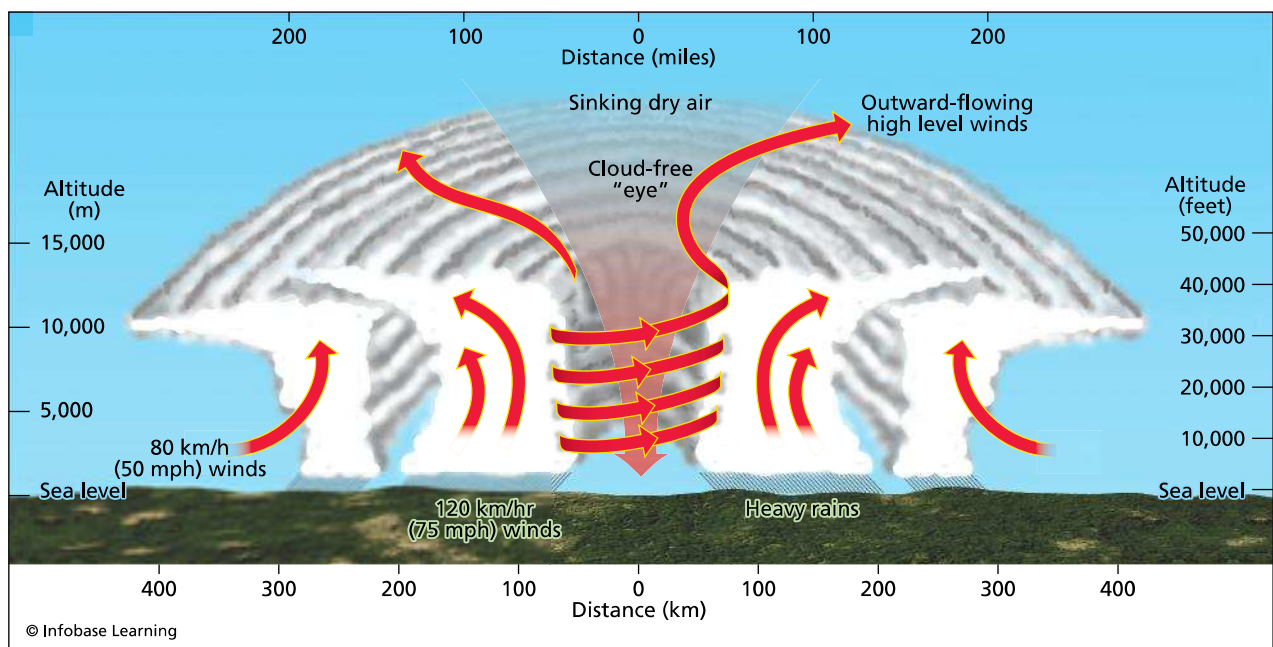


Map of the world showing the areas of typical tropical storm generation and their typical paths. These storms have different names depending upon where they are generated, but they all have the same general characteristics.

- **Category 2:** hurricanes that have sustained winds of 96–110 miles per hour (154–177 km/h). These storms produce considerable damage to mobile homes, shrubbery, and trees with some trees blown down. There is also some damage to roofing material, doors, and windows of buildings as well as coastal flooding.
  - **Category 3:** hurricanes that have sustained winds of 111–130 miles per hour (178–209 km/h). These storms produce some structural damage to small residences and utility buildings with damage to shrubbery and trees, which are typically defoliated and commonly blown down. Mobile homes are destroyed. Coastal flooding may spread inland as much as eight miles (13 km) or more.
  - **Category 4:** hurricanes that have sustained winds of 131–155 miles per hour (210–249 km/h). These storms produce complete destruction of mobile homes with some complete roof structure failures on small residences and extensive damage to doors and windows. Areas lower than 10 feet (3 m) above sea level may be flooded, requiring evacuation of residential areas as far inland as six miles (10 km).
  - **Category 5:** hurricanes that have sustained winds greater than 155 mph (249 km/h). These massive storms produce complete roof failure on many residences and industrial buildings and some complete building failures with small utility buildings blown away. They also produce major damage to the lower floors of all structures less than 15 feet (4.6 m) above sea level and within 1,500 feet (462 m) of the shoreline. All residential areas on low ground within five to 10 miles (8–16 km) of the shoreline must be evacuated in most cases.
- The vast majority of hurricanes are category 1 storms with an exponential decrease in occurrence with increasing category numbers. In other words, category 5 storms are very rare. Hurricane production varies from year to year but was somewhat cyclical during the 20th century with some years producing many strong storms and others not producing many or any at all.

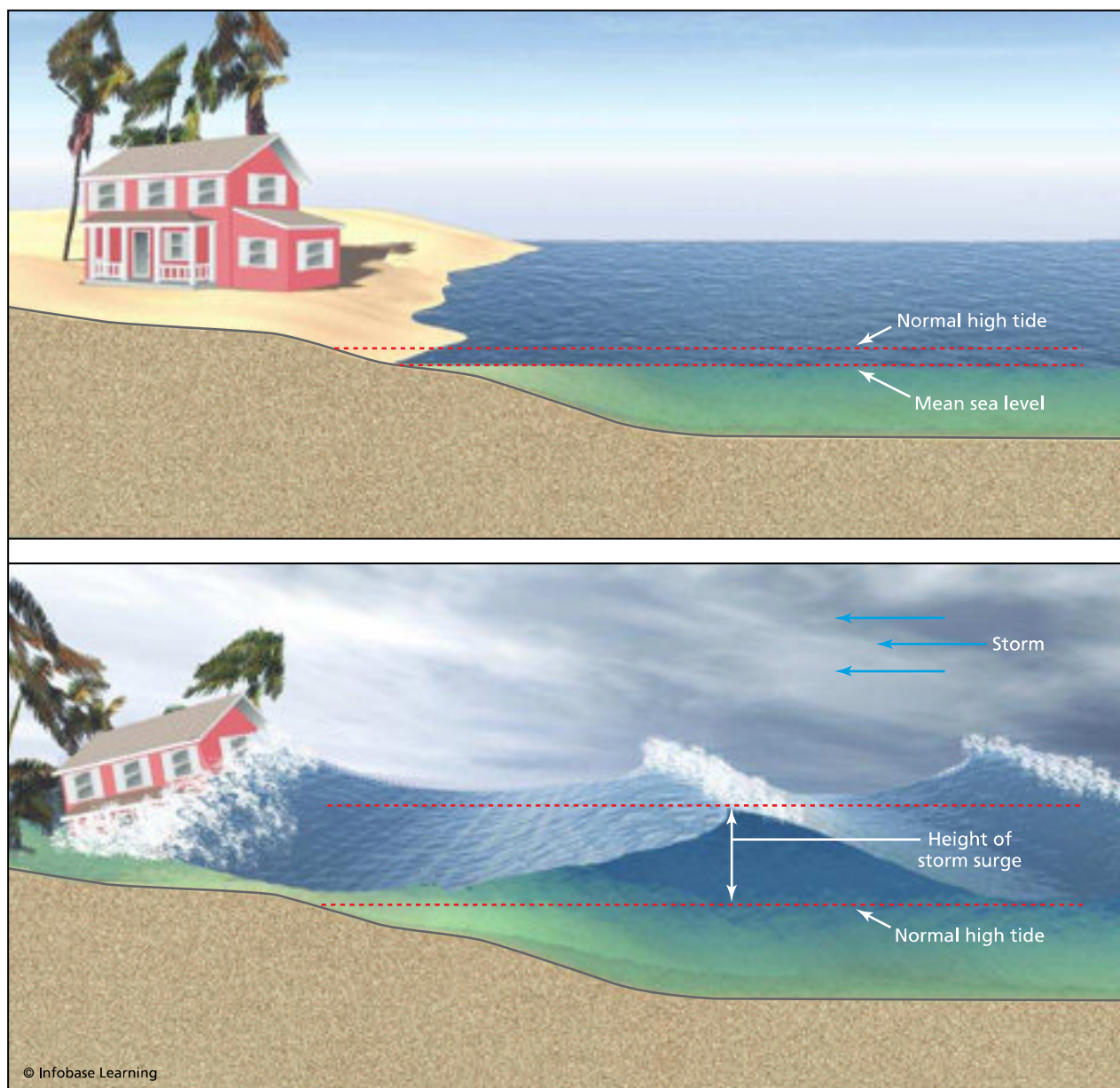
### HAZARDS OF HURRICANES

When hurricanes make landfall, there are several hazards that produce the damage. These hazards include high winds, storm surge, heavy rains, and tornadoes—these hurricane hazards lead to pollution and environmental damage.



**Illustration of a cutaway of a typical hurricane.** The graphical aspect shows the size (height and width) of the storm, and the illustration shows the anatomy of the storm including wind circulation patterns.





**Illustration of how storm surge impacts homes along coastal regions and how the storm surge height is calculated**

### High Winds

Hurricanes have very high wind speeds by definition. The highest wind speeds are those around the eye from about 25 miles (40 km) to 150 miles (240 km) outward from the center. The counterclockwise rotation coupled with forward movement results in a high-speed and a low-speed side of the hurricane. Most hurricanes move northward in the Northern Hemisphere. In this case, on the right side of the storm, the forward speed adds to the sustained wind speed to produce an increased wind speed relative to the average wind speed of the storm. On the left side of the storm, the forward momentum of the

storm decreases the wind speed by that amount. This effect is especially important in fast-moving storms. If a category 3 storm with wind speeds of 125 miles (200 km) per hour moves northward at 45 miles (72 km) per hour, the right side will have wind speeds of 170 miles (272 km) per hour while the left side has wind speeds of 80 miles (128 km) per hour. This means that in most cases, the right side is the dangerous side of the storm and all of the hazards are enhanced.

The high winds destroy buildings, storage facilities, and manufacturing plants. They destroy power lines and telecommunications service of all types



and can even damage other types of transmission and transportation lines if they are aboveground. They can overturn trucks and even railroad cars in some cases. It is these types of destruction that are most likely to cause chemical spills and related types of pollution on high ground.

They can also damage oil platforms and other distribution facilities. These structures are commonly out to sea or along the coast where the hurricane is still relatively strong. This strength means that the winds will still be at peak velocity. The damage will be compounded by the storm surge because it is driven primarily by the velocity of the wind.

### Storm Surge

The combined effect of the forward motion of a hurricane and the high wind speed forms a dome of water some 50–100 miles (80 to 160 km) wide on the surface of the ocean. This dome moves with the hurricane and strikes the coast as the storm surge. The height of the storm surge is typically included as part of the Saffir-Simpson scale. Category 1 storms have an estimated surge of 4–5 feet (1.2–1.5 m); category 2 is 6–8 feet (1.8–2.5 m); category 3 is 9–12 feet (2.8–3.7 m) above sea level; and category 4 is 13–18 feet (4–5.5 m) above. The highest is a category 5, which is more than 18 feet (5.5 m) above normal.

The reality is that the height of the storm surge striking land does not just depend upon the wind speed. It also depends upon the slope of the seafloor off the coast. A shallow drop-off means much more water able to be pushed into the storm surge, more bottoming out and rising up of the waves, and very little chance for water to escape from beneath, thus draining the dome. This produces larger storm surges. It also depends upon the shape of the coastline. Concave coastlines and harbors or bays focus the incoming waves to increase their height and speed. This is the same effect that increases the power of tsunamis. If the shoreline is convex, the waves will be dissipated because their energy is spread away. There are other factors such as tides and angle of incidence of the storm that also affect the storm surge that goes ashore. Certainly, the glancing blow of a hurricane traveling quickly northward along its left side will produce a much lower surge than a head-on landfall.

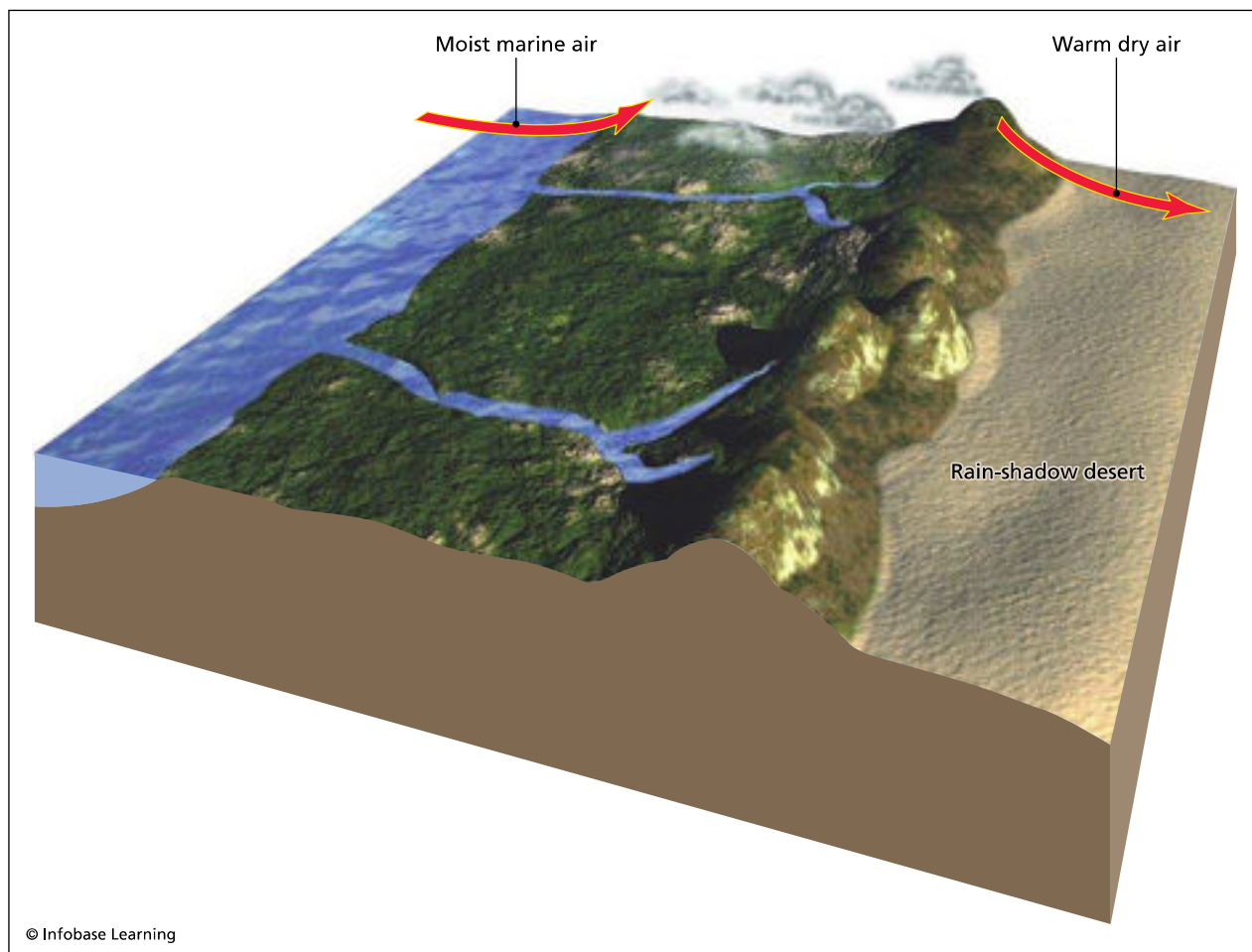
Storm surge produces heavy damage to all structures along the coast. The distance that the surge penetrates inland depends upon the topography of the coastal region. In flat areas, a strong storm surge may penetrate inland by a half-mile (0.8 km) or more. The strong waves flatten all but the strongest of structures and flood all others with salt water. All utility transmission lines are damaged or severed, and above-

ground chemical storage facilities may be washed off their footings. Refineries and oil production facilities located along the coast can be badly damaged or destroyed. The salt water, which may stand in puddles for several days or more, kills all but the hardiest of surviving plants and animals and deposits a layer of salt onto the soil, making it difficult to revegetate for years. The stagnant water may also breed disease, and it commonly ruins local water supplies.

### Heavy Rain

Hurricanes generate massive amounts of rain as they move ashore. The total rainfall depends upon the storm, but it is at least 6–12 inches (15–30 cm) and up to 40 inches (102 cm) depending upon conditions. The first factor depends on the size and intensity of the storm. Large storms with lower pressure carry more rain. Rains are generally heaviest with slower-moving storms because of longer periods of rain. The final main factor is topography. As air is driven up hill and mountain slopes, it tends to cool. The cooling causes increased condensation and heavier rain in a storm. This effect is called orographic precipitation. Certain areas are prone to this and suffer greatly if a hurricane pushes inland. Central America is such an area, where westward moving storms encounter the volcanic mountains of the western side. Hurricane Mitch, for example, dumped 40 inches (102 cm) of rain there, causing massive floods and mudslides and more than 11,000 deaths. The same effect occurs when storms move inland from the east coast of the United States. Rainfall totals increase dramatically as the storms move up the eastern slopes of the Appalachian Mountains, causing severe flooding primarily in North Carolina and Virginia.

Inland flooding has been the primary cause of tropical cyclone-related fatalities over the past 30 years. It can also cause tremendous environmental damage. Perhaps the most colorful of such events occurred when Hurricane Floyd struck North Carolina and flooded out the many lagoons of hog waste that had been located along the rivers. The hog waste floated down the rivers mixed with carcasses of drowned hogs. Less colorful but perhaps more dangerous are the washing out and overflowing of landfills, including Superfund sites. This is especially true in areas where hurricanes are uncommon and proper precautions have not been taken. The high water results in high fluid pressure on septic systems and sewers that can cause them to back up and spill onto the surface or into homes. Flood damage to buildings, chemical storage facilities, utility transmission lines, refineries, gas stations, and a number of other structures can cause spills and leaks.



**Block diagram illustrating orographic precipitation. As air is forced over an elevated area, it rises similarly to a low-pressure system and precipitation is produced. Once the air passes over the area, it carries less moisture and passes downward similarly to a high pressure that produces no precipitation.**

The result is a toxic soup of stagnant water mixed with pollutants and various diseases depending upon location.

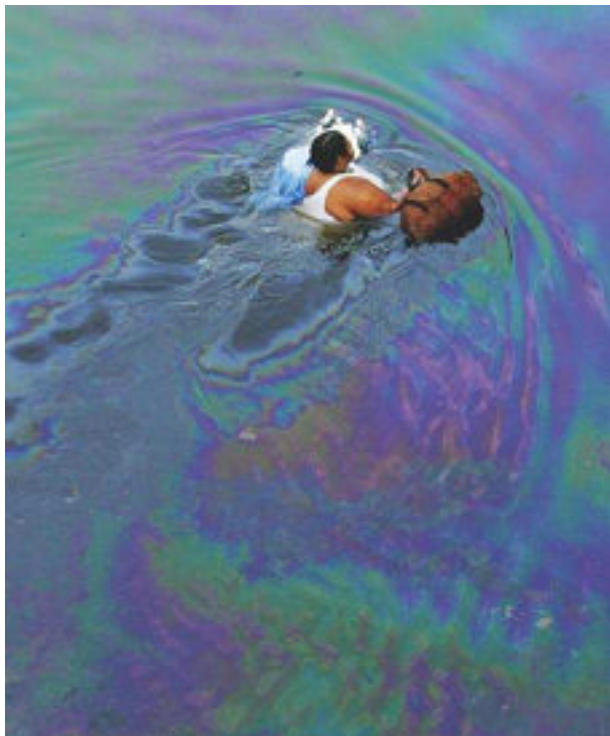
### **Tornadoes**

The rain bands on a hurricane contain embedded thunderstorms, some of which can be severe. The severe ones can spawn tornadoes. They most commonly occur in the right-front quadrant of the hurricane, which is the high-wind-speed part. The more intense a hurricane is, the greater the tornado threat. These tornadoes usually develop within 150 miles (240 km) of the coast because the hurricane loses much of its intensity after moving inland.

Tornadoes can cause catastrophic disruption of utilities and damage to buildings, storage facilities, and essentially all permanent structures depending upon their strength. Pollutants can be readily discharged into the environment during a tornado. They can uproot trees and demolish whole forests,

upsetting local ecosystems for years to decades. The amount of debris generated by tornadoes is great and litters the landscapes of impacted areas for years.

These catastrophic effects of hurricanes are the main causes of environmental damage. Depending upon the area that is struck, the reports of releases to the U.S. Coast Guard, which handles them, can number in the dozens. Most of the releases are relatively small, but a few can be large, and, taken together, a significant amount of environmental pollution can result. After Hurricane Katrina in 2005, New Orleans was said to be awash with “toxic soup,” which is standing water that has been tainted with raw sewage and chemicals from the releases and allowed to ferment. There were 25 reported chemical releases of 50 barrels (2,600 gallons [9,880 L]) or more during this storm, all of which required remedial action. Hurricane Ike struck the Houston area in 2008 and generated 51 pollution reports, 15 of which required action. The more coastal development in the



**A New Orleans resident wades through oil-covered floodwaters in downtown New Orleans, Louisiana, after Hurricane Katrina, August 30, 2005. (AP Images)**

Southeast and the Gulf of Mexico, the more numerous and serious the pollution incidents will be in the wake of hurricanes. The possibility looms that a major environmental disaster could result from such a storm, especially if a large storm strikes an oil platform, oil refinery, nuclear power plant, toxic chemical depot, or any number of military installations.

### GLOBAL WARMING AND HURRICANES

The 2005 hurricane season was the worst in recorded history. It had the most storms, the most category 5 storms, and the most damage from storms ever in the United States. In particular, the devastating impacts of Hurricanes Katrina and Rita striking the same area within one month sent shock waves across the country. Proponents of global warming were quick to use this season as a warning to Americans that if the use of fossil fuel were not curtailed, this would be a common occurrence. There was a general panic among southern coastal residents as a result.

The theory that increased storms a result from global warming posits that increased air temperatures lead to increased ocean surface temperatures. If a larger region of the ocean has surface temperatures above 79°F (25°C), hurricanes will have a greater area to power up, thus becoming ever stronger. If warmer temperatures spread farther up the eastern seaboard, stronger hurricanes can strike farther northward in the Northeast, which is usually somewhat protected by the cooler ocean temperatures. Opponents of the increased storms theory have argued that the increased temperatures will also increase wind shear, strength of fronts, and other effects that degrade hurricanes.

The 2006 and 2007 seasons had few and weak hurricanes, and the panic faded away. The problem is that hurricane formation is cyclical. There are periods of many and intense hurricanes and periods of few and weak hurricanes. Even if hurricanes increase in number and intensity, they will not do so every year. There will just be more bad years and more dangerous storms over time. The global warming proponents may be correct in their predictions over the long term, but the short-term lack of results has cost them credibility.

See also BEACHES; GORE, AL; GLOBAL WARMING; HURRICANE KATRINA; TIDES; WAVES.

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# I

## **I-10 Truck Stop, Arizona Tonopah, Arizona 1997 Soil Pollution**

There is a truck stop and service area on I-10 westbound, about 50 miles (80.5 km) from Phoenix, at the intersection of Harquahala Valley Road in Tonopah, Arizona. As do many such facilities, this truck stop stored diesel fuel and gasoline in underground storage tanks (USTs). In 1997, as part of a U.S. Environmental Protection Agency (EPA) mandate, USTs at fuel storage facilities nationwide had to be upgraded or replaced. Facility operators decided to excavate and remove the old tanks and replace them with new ones. During that process, they found that some of the tank contents had leaked and contaminated the soil that surrounded the USTs. This contamination was in an area within five to 10 feet (1.5–3 m) of the surface and along the sidewalls of the tank excavation. Concentrations of total petroleum hydrocarbon (TPH) found in the soil ranged from 72 mg/kg to 26,000 mg/kg. The Arizona standard for TPH in soil was 100 mg/kg or less.

### **CLEANUP OF THE SITE**

The environmental consultant retained by the site owners to design an appropriate remedial solution for this release selected bioaugmentation as the most technically feasible and cost-effective way to address the soil that contained elevated levels of TPH. Bioaugmentation, also called microbe seeding, is a remedial technique that accelerates the bacterial degradation of organic compounds through the introduction of nonnative, specially cultivated, or even genetically engineered microbes into the subsurface to break down the contamination. In addition to trying to control or manage the “limiting conditions”

of bacterial growth including water, oxygen content, and pH, some remedial engineers supplement or augment the native bacterial population with microorganisms that are especially suited to degrading the contaminants of concern to speed the cleanup process. Researchers and companies develop these special bacteria basically in two ways. They attempt to duplicate a spill in a laboratory and then grow or cultivate bacteria that are most effective in remediating the contaminant. They also look at various bacteria and try to combine their best features into a single type by combining various deoxyribonucleic acid (DNA) strands.

At the I-10 site, the engineers began by drilling eight six-inch- (15.2-cm-) diameter boreholes about 12 feet (3.7 m) deep into the contaminated zone. Eight four-inch- (10.2-cm-) diameter perforated pipes then were installed in these boreholes. A mixture of 150 pounds (68.04 kg) of 20-20-20 fertilizer (20 percent nitrogen, 20 percent phosphate, and 20 percent potassium) and 4,200 gallons (15,899 L) of water was injected into the eight perforated pipes. Several weeks later, 330 gallons (1,249 L) of a proprietary microbial culture containing six types of bacteria and one type of yeast was mixed with 1,000 gallons (3,785 L) of water and pressure injected into the perforated pipes. At the same time, a sprinkler system was set up to keep the soil moist. A second injection was done about a month later, and, after 60 days of treatment, a round of soil samples was collected and tested for the presence of TPH. Laboratory results indicated that in the 11 samples tested, TPH levels had been reduced an average of 96 percent, with almost half the samples now containing TPH concentrations below the state cleanup standard.



Several conditions were present at this site that made bioaugmentation an appropriate remedial choice. The soil is predominantly a “clean” sand that does not contain much silt, clay, or organic material eroded from the surrounding volcanically formed mountains. The lack of significant organic matter tends to keep native bacterial populations low. Also, this part of Arizona is dry and hot, receiving about seven inches (17.8 cm) of rain per year with an average temperature of 70°F (21.1°C). The rain that reaches the ground tends to evaporate quickly. Low soil moisture is another factor that tends to limit the types and amounts of native bacterial populations.

Remedial engineers are still evaluating the need for and effectiveness of bioaugmentation. Proponents maintain that bioaugmentation is the best way to control the character of the biomass. The random mix of bacteria in the soil at a spill site is often not capable of fully remediating the release. Another advantage of matching selected bacteria to specific types of contaminants is that remediation time frames can be accelerated. There is no adjustment or adaptive period needed, so the non-native bacteria can begin degrading the contaminant immediately. This is especially important in time-sensitive applications, such as oil spills that might enter reservoirs or aquifers used as sources of drinking water.

Some scientists maintain that there is no clear evidence that these special bacteria do a better job than those already present in the soil. Opponents point out that the use of bioaugmentation includes the addition of large amounts of electron acceptors and nutrients, and native bacterial populations might just as well cause the contaminant-degrading effects. Also, because bacteria populations are so diverse, they are much better able to respond as contaminants degrade in the subsurface.

See also BIOREMEDIATION; IN SITU GROUNDWATER REMEDIATION; UNDERGROUND STORAGE TANK.

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**imidacloprid** Albert Einstein is credited by some as having said that aside from nuclear war, the greatest challenge to human beings would occur if the bee populations were to be destroyed. Were that to occur, he predicted, humans would be able to survive as a species for a mere four years after this event. The thinking process behind this prediction is that bees do the vast percentage of pollination in the world and that without them plants would not be able to reproduce. Without vegetation, animals would die, and eventually humans would all die also. Whether Einstein actually made this claim or even had the interest or expertise to do so is debatable. This apocalyptic situation, however, actually began to happen at the beginning of the 21st century. Although the populations of wild bees had been steadily decreasing since the early 1970s, at this time, both wild and domestic bees suddenly began to disappear at an alarming rate. The direct cause was named colony collapse disorder (CCD), because entire colonies simply disappeared, rather than slowly weakening. Losses in some areas of the United States have been in excess of 90 percent, which is in the range of catastrophic, and all areas of the country have experienced significant losses of bee populations. It is estimated that in summer 2007, one-third of the remaining North American bees died off. The phenomenon has perplexed beekeepers and scientists alike and was blamed on a number of speculated causes from disease to parasites. These natural causes were probably wishful thinking by humans so as not to perceive themselves as the culprits. Recent studies suggest that this is likely not the case. New evidence suggests the direct cause may be the pesticide imidacloprid, and, as a result, it is in the process of being banned in several countries. Whether it is too late remains to be seen.

#### PROPERTIES, USES, AND PRODUCTION

Imidacloprid is a general use systemic chloronicotinyl insecticide that occurs as colorless crystals with a weak odor. It is available as dustable powder, granules, flowable slurry concentrate, suspension concentrate, soluble concentrate, and wettable powder. Commercially available products that contain

imidacloprid include Admire, Condifor, Gaucho, Premier, Premise, Provado, Winner, and Marathon. It is used to control sucking insects such as aphids, thrips, whiteflies, termites, turf insects, soil insects, and some beetles in agricultural applications. It kills insects through dermal contact and ingestion by selectively blocking neuronal pathways, causing buildup of acetylcholine, which leads to paralysis and death. Agricultural applications of imidacloprid are typically on rice, cereal grains, maize, potatoes, vegetables, sugar beets, fruit, cotton, hops, and turf. It is also effective against fleas and is used on pets and some livestock.

Imidacloprid is a relatively new pesticide that was developed after many of the traditional pesticides had been banned. Bayer CropScience introduced imidacloprid in 1991 and registered it for use in the United States in 1994. Since then, it has become extremely popular, becoming Bayer CropScience's leading product because its formulation makes it deadly to insects but far less toxic to mammals and humans. It is now one of the most widely employed pesticides, used in more than 120 countries worldwide on more than 140 agricultural crops.

### ENVIRONMENTAL RELEASE AND FATE

As with any other pesticide, imidacloprid is primarily released as a nonpoint source pollutant with minimal accidental point source releases from manufacturing, transportation, and storage. It does not evaporate readily and appears not to be transported easily from areas of application. It is also readily degraded by photolysis, and, as a result, it is not considered to be a problem in air. The main medium of concern is soil. Imidacloprid binds moderately to soil in the top few inches but less so in deeper horizons. The removal half-life varies widely depending upon soil type, fertilizers, and ground cover. The most commonly reported dissipation half-life is 26.5–48 to 190 or 229 days under field conditions, although it has persisted for an astonishing 997 days under aerobic laboratory conditions with breakdown through chemical reactions. It apparently is removed more quickly if there is a soil cover, such as in turf (dissipation in 21–33 days), and much more slowly in agricultural or fallow fields (one to two years), especially if it contains natural fertilizer such as manure or is at higher pH. Leaching of imidacloprid into groundwater is considered to be slow and minimal, although it has been found in well water in several places, including New York and Colorado. Leaching appears to be quicker in sandy soils and inhibited in organic-rich soils. Hydrolytic removal half-life in groundwater has been reported

to be 30–44 days at neutral pH and much quicker under very basic conditions ( $\text{pH} > 11$ ). Breakdown of imidacloprid in surface water has been reported to range from three hours to 14 days with breakdown by exposure to sunlight (still water) to much longer than 31 days with increasing times under neutral to slightly basic conditions and turbulent conditions. It has been found in surface waters in both New York and Florida.

Imidacloprid is toxic to upland game birds as well as ducks and others, but it was found that most birds would simply avoid coated seeds after experiencing gastrointestinal distress and loss of coordination after ingesting them. It is considered to be of moderately low toxicity to fish but very high toxicity to aquatic invertebrates. It is not very toxic to mammals. Imidacloprid is highly toxic to bees, wasps, and hornets, especially if it is applied during plant flowering. In the past, it was not considered to be hazardous when used as a seed treatment. Plants, however, readily take up even the smallest amounts of imidacloprid residues and distribute them throughout their structures including into the pollen. The new information on its persistence in soils suggests that even seed treatments may be dangerous. In addition to reduced activity, one of the main effects on bees is to disorient them. It is thought that many simply cannot return to the hive. There are many other symptoms that are appearing with CCD, including catastrophic breakdown of the bees' immune system. It is still hotly debated whether imidacloprid is the lone culprit in CCD or even a contributor. Several of the metabolites of imidacloprid are even more toxic than the parent.

### HEALTH EFFECTS FROM EXPOSURE

The U.S. Environmental Protection Agency (EPA) classifies imidacloprid in toxicity class II, which is moderate, and in class III among pesticides (scale is I–IV). Acute exposure to imidacloprid causes fatigue, apathy, muscle twitching, cramps and weakness, loss of coordination, and labored breathing. It may cause coma and death in extremely high doses. Chronic exposure at high dosage has been shown to produce thyroid lesions, weight loss, irritation of the liver, and retinal damage. Exposure of pregnant laboratory animals resulted in decreased weight of newborns and some skeletal abnormalities. The EPA classifies imidacloprid as a group E carcinogen, which is the lowest for those substances where there is evidence of noncarcinogenicity for humans. It is also only weakly mutagenic to a few cell types in laboratory tests, including human cells.

### REGULATIONS ON HUMAN EXPOSURE

The frightening part of the problem with imidacloprid is that it is not regulated by any federal agencies because it is not particularly toxic to humans. The EPA does not regulate it except in requiring labeling. The only place where the use of imidacloprid has even been restricted is France, where beekeepers convinced the government to ban its use on sunflowers after suffering heavy losses of bees beginning in 1997. The restrictions have continued, but, because the ban does not extend to any other crops and the replacements are also toxic to bees, the damage to bees has not abated. A similar legal battle is now taking place in Nova Scotia, Canada, where imidacloprid use on potatoes is being blamed for severe bee losses and consequent devastation of their blueberry crops. To date, nothing has been done to stop the problem, primarily because it is not proven that imidacloprid is the actual culprit for CCD.

See also PESTICIDES; POINT SOURCE AND NON-POINT SOURCE POLLUTION.

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**impacts, extraterrestrial** Although they are very rare, impacts of large extraterrestrial objects with the Earth can cause the most apocalyptic of environmental disasters. Prior to the 1970s, no one

even considered large extraterrestrial impacts to be in the realm of possibility. Then, a geologist named Walter Alvarez set out to determine the cause of the extinction of the dinosaurs and many other marine and terrestrial organisms at the Cretaceous-Tertiary boundary, about 65 million years ago. He went around the world studying sedimentary strata that record this period. With his Nobel Prize laureate father, the physicist Luis Alvarez, he proposed that all the data pointed to an extraterrestrial impact at the boundary. This announcement caused a revolution in geology, and, for the next two decades, scientists would amass a compelling collection of data supporting the impact. A crater would even be identified off the north coast of the Yucatán Peninsula in the Gulf of Mexico, called Chicxulub. Evidence of many other large impacts around the world would also be discovered, and suddenly the impossibility became a probability.

The occurrence of impacts should really not be surprising. The building of the planets from a rotating mass of nebular debris was based upon impacts. The plate tectonic and weathering systems of the Earth have removed all of the evidence of this early history. Mercury and the Earth's Moon, however, among other bodies, preserve extensive evidence that planetary bodies were accreted from tens of thousands of major impacts to achieve their size. These early impacts were large enough to knock large pieces off already formed planets. A popular theory is that the Moon was actually once part of the Earth but was removed as the result of a large impact. More recently, meteorites on Earth were found to have Martian affinities. It was hypothesized that a large impact on Mars may have ejected material high enough to escape the gravitational grip of the planet and that that material subsequently collided with Earth.

Not all scientists were surprised by Alvarez's revelations. Eugene Schumacher studied the Barringer crater (also known as Meteor Crater) in Arizona and fully described the process by which large extraterrestrial bodies impacted the Earth. He was the chief geological instructor for the National Aeronautic and Space Administration's (NASA's) Apollo program, which instructed astronauts how to negotiate craters and how to sample the rocks during lunar landings. Later, initially on his own, he began a program to search for extraterrestrial bodies that could impact the Earth. One of the discoveries that he made during this research was that a large comet appeared to be headed toward Jupiter. As the comet entered the atmosphere, it broke into a number of pieces. Soon after, in July 1994, humans had visual evidence that large bodies could still impact planets,





**Meteor Crater in Arizona** (François Gohier/Photo Researchers, Inc.)

as the pieces of the Schumacher-Levy 9 comet collided with Jupiter. The impacts were catastrophic to Jupiter, and scars in its atmosphere were visible for 14 months afterward. Although Jupiter is a much larger planet than Earth with a much larger gravitational field to capture space bodies, the impact caused humans to take notice and devote more effort to scanning the skies for extraterrestrial objects. Several disaster movies featuring asteroids colliding with Earth were released after the event as well.

### EXTRATERRESTRIAL BODIES

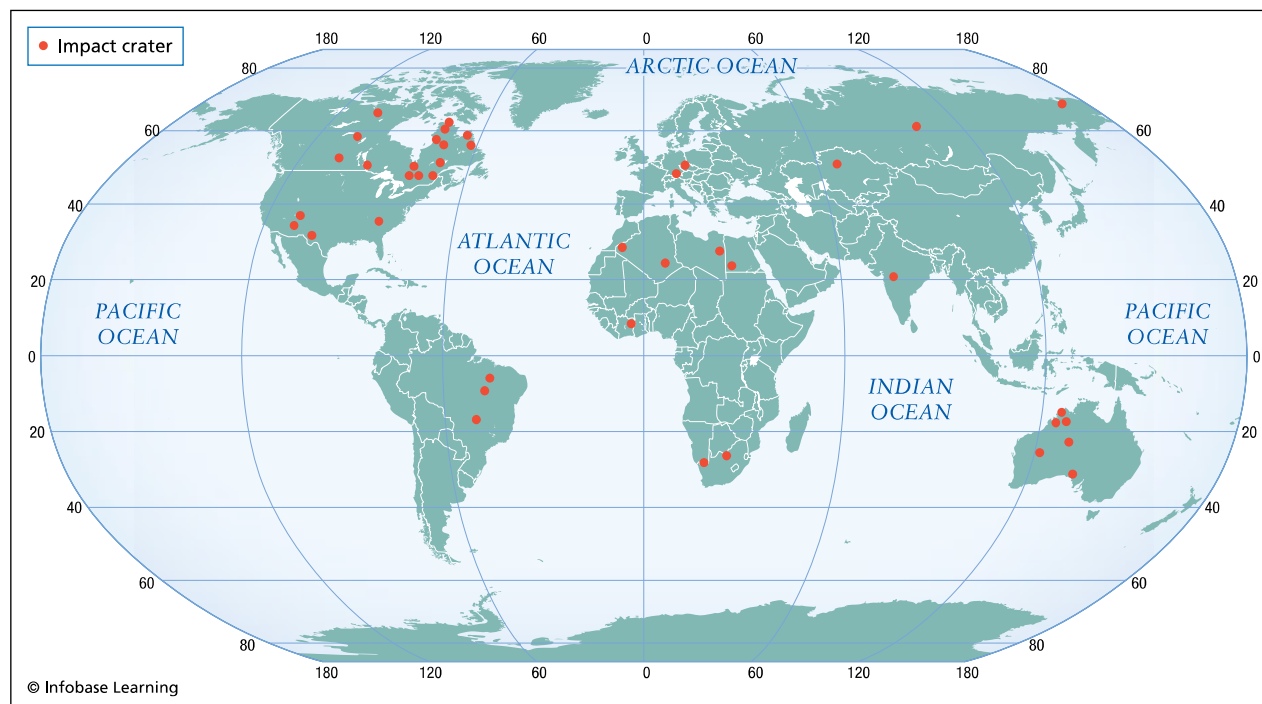
There are several types of extraterrestrial bodies that could collide with the Earth classified by size and composition. The largest of the dense bodies is an asteroid. There is a belt of asteroids between Mars and Jupiter that forms a ring around the Sun. Apparently the solar system looked similar to Saturn at one point in its development, and the rings provided the material for accretion of the planets. Asteroids range from 33 feet (10 m) to 621 miles (1,000 km) and are stony and carbonaceous (C-type), metallic (M-type), or some mix of the two (S-type), though there is evidence that some are ice bearing. There

are approximately 700,000–1.7 million asteroids with a diameter of 0.6 mile (1 km) or more in the asteroid belt. The largest asteroid by far is Ceres, which should really be classified as a planetoid. At 578 miles (933 km) across and containing about 25 percent of the mass of all the asteroids combined, it is nearly twice as large as the second biggest asteroid. The next largest are Pallas, Vesta, and Hygiea, which range from 248 to 325 miles (400 to 525 km) in diameter and with Ceres constitute nearly 50 percent of the total mass of the belt. All other asteroids in the belt are less than 210 miles (340 km) across.

Several of the asteroids have orbits relatively close to Earth. Collisions among asteroids are relatively common, with the potential to knock them out of their orbit and send them into the path of other planets. Asteroids are strongly affected by the gravity of Jupiter. Any perturbations in its gravity field, even in regular variations, can also dislodge an asteroid from the belt. Asteroid impacts with the Earth are, by far, the most dangerous of all extraterrestrial impacts.

The next largest of the extraterrestrial bodies is the comet. Comets range from less than 10 feet (3 m) to more than 124 miles (198 km) in diameter. They





**Map of the Earth showing the locations of large impact craters—more than 200 have been identified.**

are generally dirty snowballs, composed primarily of ice with rock and metal debris mixed in, although some are thought to have stony cores. Comets originate either at the edge of the solar system in the Kuiper belt or far out of the solar system in the Oort cloud. Some comets break free of these areas of origin and begin making huge orbits around the Sun. Halley's Comet, the most famous of the orbiters, appears every 77 years, the time of its orbit around the Sun. As comets move closer to the Sun, they begin to melt and develop a tail of gases and debris. The comet itself is the nucleus.

Extraterrestrial bodies less than 32 feet (10 m) that are not composed of ice are meteoroids. Like asteroids, they are classified on the basis of composition as stony, metallic, or carbonaceous. Stony meteorites are chondrites and composed largely of iron and magnesium silicates. Metallic meteorites are iron and/or nickel, and carbonaceous meteorites are stony meteorites with a high carbon content. The term *meteorite* refers to a meteoroid that landed on the Earth and can be studied; it is a "shooting star," or extraterrestrial body that shines as it burns up in the Earth's atmosphere.

### ENVIRONMENTAL IMPACT

When an extraterrestrial body enters the Earth's atmosphere, it is traveling at velocities of 27,000–161,000 miles (43,200–257,600 km) per hour. At

this speed, friction with the molecules in the atmosphere causes them to heat up. In the oxygen-rich atmosphere, smaller bodies tend to burn up before they reach the ground. Comets and friable carbonaceous bodies may even explode in an aerial airburst. The most famous of these events was the Tunguska event in Siberia. On June 30, 1908, at 7 A.M., a fireball exploded with the force of 10 megatons of trinitrotoluene (TNT) or 10 hydrogen bombs about 23,000 feet (7 km) above the remote Tunguska River valley. The explosion flattened and burned 770 square miles (2,000 km<sup>2</sup>) of forest, and the noise was heard over an area of 386,000 square miles (1 million km<sup>2</sup>). It is estimated that the body was a small friable asteroid about 80–160 feet (25–50 m) in diameter and traveling at a speed of more than 50,000 miles (80,000 km) per hour. If such an explosion happens over a city, tens of thousands of people or more will be killed.

When the Chicxulub impact became a possibility in the late 1970s, the U.S. Congress held hearings on the potential environmental damage of such a disaster. Such dignitaries as Carl Sagan were included in the group. The new phrase introduced at this time was "nuclear winter," which described the effect of both a nuclear war and an asteroid impact. A large collision would pulverize the asteroid, and a huge amount of rock and soil at the impact site, and raise a huge dust cloud high into the atmosphere. The particulate from such an event would encircle the



**Map of the Gulf of Mexico and surroundings showing the location of the Chicxulub Crater on the Yucatán Peninsula, Mexico. The impact that formed this crater is believed to have caused the mass extinction at the Cretaceous-Tertiary boundary.**

planet, drastically reducing sunlight for periods up to several years. Not only is the particulate dangerous to most life on the planet through inhalation and poisoning, the lack of sunlight would eliminate photosynthesis and cause a worldwide famine.

The “smoking gun” evidence for the Chicxulub impact according to Luis Alvarez was the layer enriched in iridium. He noted that iridium is uncommon at the Earth’s well-evolved surface but much more abundant in primitive bodies such as asteroids. Although iridium has not been identified as particularly dangerous, especially in such small quantities, other elements and inorganic compounds common in primitive bodies are. Nickel is quite common in asteroids and meteoroids and is an environmental pollutant. Chromium may also be present in some meteoroids, as may titanium and other metals. In the area around the impact crater, these pollutants may be at concentrations of environmental concern, even up to minable levels. Further, the high heat and pressure at the impact may be so intense that glass fragments fine enough to cause silicosis may be abundant. Other compounds that may also be undesirable may be created.

See also CHROMIUM; NICKEL; PARTICULATE.

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**indoor air pollution** Although the common perception is that houses and buildings are clean and outdoors is dirty and potentially disease-ridden, the reality is that, in the vast majority of cases, indoor air is far more dangerous. Vast numbers of pollutants can occur indoors from a variety of sources. Symptoms of this pollution can vary from mild to severe, even resulting in terminal diseases such as cancer and death, both from long- and short-term exposure. The World Health Organization released a report in 1984 that found up to 30 percent of new and remodeled buildings generate excessive health problems. One reflection of this is sick building syndrome (SBS), a nonspecific problem in which a large percentage of people become ill within a specific building. There can be a number of causes for SBS, and all of them are some form of indoor pollution.

Although the actual number of chemicals and other components of indoor air pollution can number in the thousands, the vast majority are in negligible concentrations. Most also fall into relatively few source categories including home combustion devices/appliances, environmental tobacco smoke (ETS), volatile organic compounds (VOCs), heavy metals, biological sources, radiation, and miscellaneous sources. Home combustion includes any indoor device that burns natural gas, kerosene, wood, or oil such as gas stoves, fireplaces, gas dryers, some space heaters, and even some furnaces and water heaters, depending upon the device and conditions. ETS carries more than 4,000 chemicals that overlap many of the other categories and is by far the most dangerous of the nonbiological pollutants. VOCs can have numerous direct sources, ranging from numerous cleaners, paints, and hobbies to indirect sources such as the evaporation of plastics and even tobacco smoke. There are numerous biological sources, ranging from pet dander

to molds and fungi in moist areas to viruses and bacteria to live pests such as dust mites.

### COMBUSTION BY-PRODUCTS

Although many environmentalists would rather use natural gas in their homes because it is far more efficient than electricity, there can be more severe problems caused by indoor air pollution. This applies to furnaces, space heaters, stoves, water heaters, and dryers. The same issues arise from oil burning furnaces and water heaters, kerosene space heaters, fireplaces and woodstoves, gas lamps, and grills. The problem is that oxygen is used in combustion, and in many cases the dwelling is progressively deprived of oxygen. The by-products of burning may also be dangerous, especially if the appliance runs on too little oxygen. Partially burned hydrocarbons and oxygen-poor combustion by-products are especially dangerous to health. Although there are many compounds that fall into this category, the most common indoor pollutants that are combustion by-products are carbon monoxide, nitrogen dioxide, and sulfur dioxide. These compounds tend to occur together in many instances and produce a combination of symptoms including dizziness or headache, confusion, nausea, fatigue, eye irritation, upper respiratory irritation, wheezing and bronchial constriction, persistent cough, increased respiratory infections, and worsening of symptoms in people who have chronic circulatory, cardiovascular, and respiratory conditions (chronic obstructive pulmonary disease [COPD]). Individually, these by-products have specific indications.

#### Carbon Monoxide

Complete burning of hydrocarbons and other combustion products produces carbon dioxide. If carbon dioxide displaces too much oxygen, a person can suffocate, but this is a rare occurrence. If burning is incomplete because of lack of oxygen, carbon monoxide is produced in its place depending upon the degree of oxygen depletion. This situation is common when burning takes place in an enclosure. Carbon monoxide is a colorless, odorless gas that acts as an asphyxiant. Rather than simply displacing oxygen, it actually participates in respiration and combines with hemoglobin in the blood to form carboxyhemoglobin (COHb), thereby disrupting oxygen transport and respiration. This deficiency affects the areas of the body most in need of oxygen first, including the brain and large active muscles. Symptoms include fatigue, headache, dizziness, nausea, vomiting, confusion, and tachycardia depending upon COHb in the blood.

All these symptoms can be mistaken for influenza. By the time headache, fatigue, and impaired judgment appear, the COHb is typically at 30 percent and confusion at 40 percent. At 60 percent COHb, victims will lose consciousness and expire if they are not removed from the area in a timely manner. Death comes at lower concentrations and more quickly to people with chronic circulatory, cardiovascular, or respiratory conditions (COPD). It is this rapid onset of death that has made carbon monoxide poisoning a common choice for suicide, which is typically accomplished by sitting in a running automobile in a closed garage.

Carbon monoxide poisoning is not uncommon in homes and is especially prevalent in winter months. Faulty and malfunctioning furnaces, poorly ventilated space heaters, and leaking chimney flues are common culprits in such cases. Weather can also contribute to carbon monoxide poisoning. Under certain conditions of rising pressure in a calm system like that which might be encountered in winter or if wind conditions are ideal, furnace exhaust can be forced back down the chimney and into the house. Many deaths and serious injuries have resulted from these events. For this reason, many areas require carbon monoxide detectors in homes. Newer furnaces are much more efficient, produce very little carbon monoxide, and have exhaust systems that are not prone to weather fluctuations, so, in time, accidental carbon monoxide poisoning should become less common. In historical times, when all heating and lighting were done with combustion appliances, low-level carbon monoxide poisoning was far more common. Houses, on the other hand, were drafty and not well sealed, and, as a result, death from carbon monoxide poisoning was not as common as one would expect.

#### Nitrogen Dioxide

Nitrogen dioxide is an indoor pollutant from combustion. It is relatively insoluble in water and is, therefore, not terribly irritating to the eyes and upper respiratory tract, although there can be some reaction particularly among sensitive people. It is, however, irritating to the lower respiratory tract. Exposure can cause increased reactivity in asthmatics; decreased lung function in people who have respiratory diseases; increased risk of respiratory infections, especially in children; and even pulmonary edema and possible death at high concentrations. It has also been shown to contribute to the development of acute or chronic bronchitis. Typically, concentrations of nitrogen dioxide are relatively low in indoor air and readily removed when the combustion source is addressed. Outdoor air

typically has twice as much nitrogen dioxide as indoor air.

### **Sulfur Dioxide**

Sulfur dioxide is another indoor pollutant from combustion. Unlike nitrogen dioxide, it is relatively soluble in water and is, therefore, highly irritating to the eyes and upper respiratory tract in concentrations as low as six parts per million (ppm). Sulfur dioxide reacts with the moisture in the mucosa of the eyes, nose, and throat, producing sulfuric acid, which burns these areas. It can also cause acute bronchial constriction in people who have asthma or as a hypersensitivity reaction in others at concentrations as low as 0.4 ppm. Long-term exposure to sulfur dioxide can contribute to chronic lung disease and decreased lung pulmonary function. Typically, concentrations of sulfur dioxide are relatively low in indoor air and readily removed when the combustion source is addressed.

### **ENVIRONMENTAL TOBACCO SMOKE (ETS)**

The U.S. Environmental Protection Agency (EPA) estimates that some 38,000 people die per year of diseases resulting from exposure to ETS including 3,000 of lung cancer. ETS produces as many as 300,000 lower respiratory tract infections per year in children younger than 18 months old. Tobacco smoke is a complex mixture of numerous chemical compounds. Approximately 4,000 chemical compounds have been identified of the estimated 100,000 total in tobacco smoke. These 4,000 compounds, however, represent 95 percent of the total mass and include more than 50 known carcinogens and up to 400 toxins. Hazardous compounds in tobacco smoke include tar, arsenic, lead, cadmium, nickel, carbon monoxide, carbon dioxide, nitrogen oxides, hydrogen cyanide, benzene, ethylbenzene, vinyl chloride, dioxin, polycyclic aromatic hydrocarbon (PAH) including benzopyrene, volatile and nonvolatile aldehydes and ketones, hydrazine, quinones, butadiene, radioactive polonium, ammonia, N- and other nitrosamines, phenols, alcohol, carboxylic acid, formaldehyde, nicotine, sulfur dioxide, and various pesticides and fertilizers. There are two types of tobacco smoke that constitute much of ETS, mainstream, which is inhaled directly into the lungs, and sidestream, from smoldering cigarettes. Sidestream smoke results in incomplete burning of tobacco, which produces carbon monoxide, as well as 40–170 times the ammonia content of mainstream smoke, four to 10 times the content of nitrogen oxides, 10 times the benzene content, six to 100 times the N- and other nitrosamines, and 30 times the aniline.

Key symptoms of exposure to ETS in adults include nasal congestion, persistent cough, irritated eyes, headache, wheezing and bronchial constriction, sinus inflammation, and exacerbation of any chronic respiratory conditions. Key symptoms in children include onset of asthma, increased severity of asthma, frequent upper respiratory infections, persistent middle ear problems, snoring, and repeated bronchitis and pneumonia. These symptoms can vary from mild to severe, depending on the amount of smoking (exposure) relative to the size of the dwelling and the sensitivity of the individuals. The primary cause of these overt symptoms is the coarse particulate (particulate matter with a diameter of 10 microns or less [PM10]), whereas the chemicals and fine particulate typically cause the problems of long-term exposure such as heart disease, stroke, cancer, blood clots, and eye problems. Although there are filtering systems available that can remove the particulate and many of the chemicals, the best solution is not to allow smoking in the dwelling.

### **BIOLOGICAL AIR POLLUTANTS**

There are biological pollutants of some sort in virtually all buildings in varying degrees. It is only when these pollutants are dangerous to the occupants that they become enough of a problem that they must be addressed. Sources for these pollutants vary from viruses and bacteria on the human occupants; animal occupants including pets, insects, and vermin that shed allergens; moist areas that spawn bacteria and fungi; to influx of outdoor air and all of the biota contained within. Moist and wet areas are of special concern because they can host a large number of dangerous pollutants. Kitchens, bathrooms, basements, washing rooms, humidifiers and dehumidifiers, and certain heating, ventilation, and air-conditioning (HVAC) systems are the most common sources of microbial activity and dust mites, among others, but even wet carpets and towels can harbor problems.

There are three types of human diseases that can result from biological pollutants in indoor air: infections, hypersensitivity disease, and toxicosis. Infections result when airborne pathogens from known or unknown diseases infect human tissue. Depending on the pathogen, they can range from mild to severe and even fatal in rare cases. Hypersensitivity diseases involve the reaction of the immune system to a specific airborne irritant to which individuals are particularly sensitive. In toxicosis, toxins are produced by biological processes and released to the air, where they can affect humans in a range of ways. The key symptoms of exposure to biological indoor air pollution are vari-



able depending upon the source and type but commonly include cough, tightness of the chest, runny nose, irritated eyes, recurrent low-grade fever, malaise, exacerbation of asthma, and symptoms specific to a particular disease. The following are symptoms and sources of specific diseases.

### **Tuberculosis**

Tuberculosis (TB) is a severe degenerative disease of the lungs that is commonly transmitted through the air. It is more common in overcrowded areas with inadequate ventilation. The symptoms include cough, shortness of breath, fever, and fatigue that worsen with time, ultimately leading to death if not treated. TB was steadily declining from its first monitoring in 1953 until the mid-1980s, when it began to rise sharply. In part, this increase resulted from the expanding acquired immunodeficiency syndrome (AIDS) epidemic, the victims of which are particularly susceptible to TB. The increase in TB during this time also corresponded to increased immigration into the United States, including by people who had contracted the disease in their home country. TB germs can be carried by a person without his or her ever contracting the disease. It is estimated that about 10 million Americans are infected with TB germs, of whom only about 10 percent will develop TB disease in their lifetime. The remaining 90 percent will never get sick from TB or be able to spread it to other people. On a worldwide scale, it is estimated that nearly 1 billion people will become newly infected, more than 150 million will become sick, and 36 million will die between now and 2020.

### **Legionnaires' Disease**

Legionnaires' disease became well known in 1976 when an outbreak of "unexplained pneumonia" sent numerous people attending a convention of the American Legion in Philadelphia, Pennsylvania, to the hospital. A number of the people died, and this apparently new disease, appearing in the media on a daily basis, panicked Americans. It was, in fact, simply a more virulent version of Pontiac fever, a flu-like illness that was identified in Pontiac, Michigan, in 1968. Legionnaires' disease is a pneumonia that is much more common in individuals more than 50 years old and especially in those who smoke, drink to excess, or have problems with their immune system. The fatality rate is among the highest for those diseases caused by indoor air pollution at 5–25 percent, and death results relatively quickly. The case in Philadelphia was caused by the bacteria growing in a cooling tower, but it has been found in HVAC systems, whirlpool baths, humidifiers, vegetable mis-

ters, and even fountains and home water taps, in some cases. Between 8,000 and 18,000 people are hospitalized each year with Legionnaires' disease in the United States, but many more cases are not reported because they are misdiagnosed as influenza.

### **Allergic Reactions**

Allergic reactions in sensitive people are, by far, the major concern with regard to biological air pollutants. Allergens that trigger allergic reactions primarily arise from pet dander; house dust mites; other insects such as cockroaches, ants, and flies; mold and mildew; plants and flowers; and bacterial enzymes, algae, and furnishings that contain allergen-bearing materials such as feathers and fur. Allergens may also enter a home from outdoor air. Symptoms of allergic reactions may include runny nose, congestion, postnasal drainage, irritated eyes, labored breathing and asthma, and, in some cases, hives. Most of these symptoms are simply annoying, but asthma can be deadly and must be closely monitored. Dust mites can infest homes not only in HVAC systems but also in bedding and carpets.

### **Hypersensitivity Pneumonitis**

Otherwise known as allergic alveolitis, hypersensitivity pneumonitis is an interstitial lung disease that is caused by exposure to airborne antigens. It is serious enough that it can lead to end-stage pulmonary fibrosis. Normally, it is restricted to farmers and pigeon breeders, affecting 1–5 percent of that population, but it has also been found as outbreaks in office buildings with mold and bacteria contamination in their air-conditioning and humidifier systems. It can also occur in homes with contaminated HVAC systems and humidifiers or with pet birds. It can take years for a person to develop sensitivity to the causes of this condition, but, thereafter, he or she may experience symptoms including cough, dyspnea, chills, myalgia, fatigue, high fever, lung nodules, and an elevated white blood cell count.

### **Humidifier Fever**

Humidifier fever is similar to hypersensitivity pneumonitis in its symptoms but has a high attack rate and short-term effects that are indicative of toxins. It appears to be related to exposure to amoebae, bacteria, or fungi found in humidifiers, air conditioners, and aquariums. Symptoms appear within a few hours of exposure and include fever, headache, chills, myalgia, and malaise. They typically subside within 24 hours. The number of people affected during a given outbreak can be quite high, exceeding 25 percent of those exposed in some cases.

### Mycotoxins

Mycotoxins are fungal metabolites in indoor air that result from fungal colonies established in moist areas. Most mycotoxins are ingested in contaminated foods, but they can be present in airborne spores. The range of symptoms from exposure to mycotoxins is broad, from temporary and minor irritation including dermatitis to suppression of the immune system and even cancer.

### VOLATILE ORGANIC COMPOUNDS (VOCs)

VOCs have received much publicity concerning their potential adverse health effects, and, as a result, many common products have been reformulated to reduce or eliminate their VOC content. Nonetheless, they are still very common in household uses, and daily exposure is common. VOCs evaporate readily whether they are solids or the more common liquids. They include numerous chemicals such as benzene, formaldehyde, acetone, petroleum products and components, perchloroethylene, toluene, xylene, ethylbenzene, 1,3-butadiene, polyvinyl chloride, chloroform, and literally hundreds of others. They are found in all kinds of commonly used products such as paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions. Other household products that include VOCs are varnishes, solvents, wax, and many cleaning, disinfecting, cosmetic (hairspray, nail polish, and perfume), degreasing, and hobby products. They evaporate out of many plastic and vinyl products including carpeting and automobile upholstery. In fact, amounts of organic pollutants are typically two to five times higher in homes, cars, and offices than in outside air, regardless of whether they are located in rural or highly industrial areas.

VOCs produce a variety of symptoms ranging from mild to severe. Typical symptoms include dizziness, lightheadedness, fatigue, and headache; nose, throat, and eye irritation; and nausea, dyspnea, skin irritation in some cases, and a general decline in serum cholinesterase levels. High levels of some VOCs can result in intoxication, and, for that reason, they are used in huffing by substance abusers. Some VOCs such as benzene, xylene, and toluene are documented carcinogens and should be avoided. Some of the most notorious VOCs are formaldehyde and components of pesticides.

### Formaldehyde

Formaldehyde is classified as a probable human carcinogen by a number of regulatory agencies. It was used extensively in new house construction and renovation in the form of urea-formaldehyde foam insulation (UFFI) until the early 1980s, when it was found to be harmful. Now it is seldom used, but formaldehyde is still present in resin used in some finishes, plywood, paneling, fiberboard, and particleboard that is commonly used for building materials, components of furniture and cabinets, permanent-press fabric, draperies, and mattress ticking. As a result, most people are exposed to formaldehyde vapors on a daily to weekly basis. The most recent publicized case of formaldehyde as an indoor air pollutant was in the homes provided to the refugees from the 2005 Hurricane Katrina disaster by the Federal Emergency Management Agency (FEMA). Less than a year later, indoor formaldehyde levels in these homes were found to be above the acceptable limits.

Symptoms of exposure to formaldehyde vary from slight irritation of the eyes, nose, and throat to tightness of the throat and chest accompanied by wheezing. The more serious reactions to formaldehyde exposure may reflect hypersensitivity. It is estimated that between 10 and 20 percent of the U.S. population, including the majority of asthmatics, are hypersensitive to formaldehyde. Long-term exposure to formaldehyde greatly increases the risk of developing certain cancers.

### Pesticides

Although pesticides can fall into a number of categories of pollution, especially because they carry poison, a significant amount of VOC is released with the use of foggers and pest strips. The propellant in sprays and foggers is primarily VOC. Symptoms of exposure may include headache, dizziness, muscular weakness, and nausea, and they may be exacerbated by exposure to the poison in the pesticide.

### HEAVY METALS

There are several types of inorganic, heavy metal pollutants that can be contained in indoor air. By far, the most common and dangerous of these are lead and mercury. Most others, introduced from burning and primarily from tobacco and fireplaces or from outdoor air in rare instances, occur in extremely low concentrations. Other sources such as machine shops, garages, and fireworks displays are very specific and not common to many houses. Lead and mercury exposure have different sources and symptoms than most other metals.

### Lead

Lead has been one of the great boons and, at the same time, scourges of human civilization. It has been readily usable for a huge variety of purposes for which safe replacements have been difficult to adapt once lead was found to cause a health problem. For the past 30 years, lead has been banned from numerous common consumer applications, and yet it is still a major health concern. The main areas of concern are lead in old pipes; lead in paint, hobbies, and crafts; and lead in consumer items from other countries. Lead in paint is clearly the most important source for general indoor air pollution, although specific activities that use lead directly can yield more severe problems. In 2004, the U.S. Department of Housing and Urban Development (HUD) estimated that about 38 million homes in the United States contain some lead paint. Of these, some 24 million homes, or about 25 percent of the total, contain significant deteriorating lead paint or lead-contaminated dust. In 2002, there were still more than 310,000 children below the age of six in the United States who had too much lead in their blood, and paint dust was the main culprit. It is also estimated that many fetuses are exposed to lead in vitro.

Symptoms of lead poisoning in adults include gastrointestinal problems ranging from distress, constipation, and nausea to anorexia, fatigue, muscle weakness and tremors, personality changes, headache, hearing loss, and loss of coordination. In small children and infants, symptoms include irritability, abdominal pain, hyperactivity, short attention span, learning disorders, and, in some cases, seizures and loss of consciousness. The primary health problems are caused by long-term, low-level lead exposure, rather than acute exposure. Lead builds up in the body and has a cumulative negative effect on concentration, learning ability, and general intelligence. These long-term symptoms can be unnoticed for a long period to the point where the damage is severe and permanent.

### Mercury

Mercury is a heavy metal that was a problem in indoor air largely because lead was reduced or eliminated from paint. When lead was discovered to be the health threat that it is, the trend toward using latex paint as an alternative to oil paint increased. Many latex paints contained phenylmercuric acetate (PMA), a preservative that was a source of mercury vapor in indoor air during application and drying. As a result of increased adverse health effects, PMA was restricted to exterior paints in 1990 and banned

from all paints in 1991. Through continuing legislative efforts, mercury has largely been eliminated from most household items such as thermometers and batteries, but it may still be found in some older items. It is also still used in mercury vapor lamps for exterior lighting and some automatic switches.

Symptoms of exposure to mercury in indoor air are headache, intermittent fever, muscle cramps and tremors, tachycardia, acrodynia, personality change, and neurological dysfunction. It is these last two symptoms for which mercury exposure is most noted. Wool felt for hats used to be processed with mercury. This is the reason that the Hatter in the book *Alice in Wonderland* was mad.

### RADIATION AND ELECTROMAGNETIC (EM) FIELDS

Households are awash with EM fields and radiation. For this description, EM radiation is considered to be ionizing (X-rays, ultraviolet [UV] radiation, gamma radiation), whereas EM fields are considered to be nonionizing (electric and magnetic fields). Every appliance gives off an EM field. The strength of the field varies with the amount of electric current passed through it. Studies have suggested a link between exposure to low-frequency EM fields and onset of childhood leukemia. The rate of leukemia in children is so low and the correlation so weak, however, that the effect is still debatable. Nonetheless, there is a potential for damage from long-term, symptom-free exposure to strong EM fields.

Ionizing EM radiation is another story. The most common source are cathode-ray tubes in television sets and computer monitors. When televisions were introduced, the amount of EM radiation in the X-ray wavelengths was significant, and there was significant risk for people who watched for excessive periods. With time, televisions have been designed with better shielding, lower power consumption, and alternative projection technology, all of which have reduced the amount of EM radiation. Sources of gamma radiation in the home can be building materials, some decorative pottery, sculpture and rocks, and specialized devices (detectors, etc). There have been cases where buildings were constructed of concrete where its gravel was from uranium mine tailings. In such cases, gamma radiation exposure was high, as was radon exposure. UV radiation arises only from black lights or tanning equipment. People typically are exposed to higher doses than the indoor exposure by being out in the Sun. Lately, lasers have been used more in homes and provide yet another source of radiation. The EM radiation from

lasers is in the visible range of the spectrum and can damage the eyes if not used properly. Otherwise, all these forms of radiation are damaging only with long-term exposure, in which there are no symptoms

### MISCELLANEOUS INDOOR AIR POLLUTION

Two of the most dangerous forms of indoor air pollution do not fall into any of the other categories. Radon is considered to be the most dangerous natural environmental hazard and second only to ETS in overall danger. Asbestos is one of the few pollutants that have a certain link to cancer rather than just an indication through epidemiological studies. Both of these pollutants are a concern only in indoor air. Outside, in almost all cases except around mines, they are far too diluted with fresh air to be a real problem.

#### Asbestos

Asbestos was once considered a miracle mineral, and, as such, it was widely used. It is composed of very long hairlike fibers that are resistant to flame and heat. For this reason, asbestos was used in a variety of applications that required flexible strength and/or heat resistance. It was used in brake pads and clutch plates in automobiles; insulation for heating systems; gloves, tongs, and many other devices for working with flames and fires; in ironing boards, stoves, hair dryers, and other household heating devices; and in floor tiles and house shingles, among many other applications. Asbestos was recognized as a problem only after shipbuilders who had sprayed finely ground asbestos on ship panels during World War II began to sicken in unusual numbers. They had asbestosis, or scarring and fibrosis of the lung tissue, from heavy occupational exposure to fine asbestos fibers.

There are many kinds of asbestos. By far the most common is chrysotile, which makes up more than 90 percent of all asbestos and is linked to asbestosis. Crocidolite is a much less common form of asbestos that has also been linked to mesothelioma, a rare asbestos-related lung cancer. Usually, asbestos-related diseases are considered to result from a lifetime of heavy exposure, although there is strong debate about this point. Otherwise, there are no symptoms of asbestos exposure. It is suggested that there is a synergistic relationship between smoking and asbestos exposure, increasing the risk of lung cancer up to fivefold.

For many years, when asbestos was found to be present in buildings and homes, it was removed. It was found, however, that the removal process put

far more asbestos into indoor air than would have happened had it just been left alone. As a result, the recommendations were changed to encapsulation of the asbestos-bearing feature such as pipes where possible as long as it is intact.

#### Radon

Radon is a naturally occurring colorless and odorless gas that exists in most indoor air. It is produced during the radioactive decay of uranium 238 through a decay series to lead 206, a natural process that takes place continuously in most rock and soil. One step in this decay series is radium 224, which decays to radon 222. If the radium atom is on the surface of a mineral grain, the decay will eject the new radon atom into the open pore space and into soil gas or groundwater. Radon is the only gas in the decay series. The radon can be drawn into the basement of a house through cracks, French drains, sumps, or dirt floors by any process that reduces the pressure in the basement. The most common of these occurs in winter when a house's heating system heats the indoor air, making it less dense and causing it to rise, thus drawing soil gas into the basement. Houses with well water may also have additional radon introduced into the house through the water supply. The radon that was released to the groundwater is liberated to indoor air if the water is agitated, such as in a shower, washing machine, or dishwasher among others.

Radon is a noble gas, and, as such, it will not react with anything; nor can it be filtered using conventional methods. That is why it does not simply react with the soil and remain in the ground. The radon itself is harmless but decays to form polonium at a rate of 3.82 days per half-life. Polonium is a highly charged solid that sticks to lung tissue or to dust in the air, which is then breathed into the lungs. The polonium decays in a matter of seconds, emitting 7.6-MeV alpha decay. Normally, alpha decays are harmless because they can only travel 0.5–1 inch (1–2 cm) before expending their energy. If attached to lung tissue, however, they can cause mutations in the nearby cells. A sufficient total of mutations can develop into lung cancer, especially if the cells are already weakened from smoking.

The U.S. Environmental Protection Agency recommends an action level of 4 picocuries per liter. Below this, no action is required, but, at or above it, remedial actions are recommended. The level of 4 picocuries per liter over a lifetime of exposure is suggested to increase the risk of lung cancer. Otherwise, there are no other symptoms of radon exposure regardless of its concentration.



See also ASBESTOS; CARBON MONOXIDE; FORMALDEHYDE; LEAD; MERCURY; PESTICIDES; RADIATION; RADIUM; RADON; SULFUR DIOXIDE; TOBACCO SMOKE; VOLATILE ORGANIC COMPOUND.

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**influent/effluent streams** Streams are flowing bodies of water that occur on the surface of the Earth. They begin at the headwaters, typically in elevated terrains where several smaller streams coalesce to form larger streams. The smaller streams are tributaries, and there is a ranking system of orders, in which a first-order stream is the main trunk, and smaller streams have higher numbers of orders. Streams are fed by drainage basins, which are areas of lower elevation topographically bounded by drainage divides. The watershed of such an area includes the groundwater component, as well as the surface water. The water in a stream may be from runoff during precipitation events, runoff from thawing of ice and snow, or input from groundwater sources.

Groundwater is primarily recharged from infiltration of rainwater or meltwater into the soil. It passes through the *vadose zone*, which is rock and soil that are normally dry but through which water percolates, and into the *phreatic zone*, which is rock and soil that are constantly saturated with water. The top of the phreatic zone is the *water table*, whose height (depth) varies with the season and precipi-

tation events. As does surface water, groundwater flows down slopes but in the subsurface and at much slower rates. The rate is dependent upon the type of soil, sediment, or rock through which the groundwater flows. More precisely, it is the properties of the material, the hydraulic conductivity and transmissivity, in conjunction with the slope that determine the rate of groundwater flow. The topography of most areas, the hills and valleys, can be used to determine flow direction and relative rate of the groundwater and surface water. Streams interact with the groundwater system in a very intimate relation.

#### **INFLUENT OR EFFLUENT STREAMS**

If water infiltrates the bed of a stream and enters the water table, thus reducing the surface water and increasing the groundwater volume, the stream is termed *influent*, because it flows into the water table. Influent streams are common in dry areas, where the water table tends to be deep. The vadose zone is large and deep in these areas. Surface water in these areas is the major mode of recharge for groundwater in the shallow aquifer. The process has the effect of reducing the size of the stream as it flows toward the mouth, which is the opposite of what would normally be expected.

By contrast, if groundwater emerges from a spring in the bed or side of the stream, thus increasing the surface water at the expense of the groundwater, the stream is termed *effluent*. This volume of water in the stream that originated from groundwater is called *base flow*, and it constitutes the major water component of the stream. Base flow allows streams to keep flowing even when there has been no rain for a long time. The springs, or seeps, in or around the stream are areas where the water table intersects the ground surface. This situation requires a very shallow water table, which, in turn, requires significant and regular precipitation in the watershed to keep the volume of groundwater high. Vadose zones in these areas are thin and small.

Whether a stream is *influent* or *effluent* is a matter of location and time. A stream may be *influent* during a dry season and *effluent* during a rainy season. In some streams, even daily precipitation can switch a stream from *effluent* to *influent*, and vice versa. Influence versus effluence may also vary from location to location along a stream. A stream may be *effluent* at its headwaters but *influent* farther down along its course, for example. This dichotomy is typical of streams that flow out of mountains and across dry areas such as in the southwestern United States. There are any combination of conditions of influence and effluence along the length of a stream. The sys-



**A lagoon such as this located in the former German Democratic Republic can be used to store large quantities of wastewater prior to treatment. It can also act as a source of groundwater and surface water contamination if not properly managed. (imagebroker/Alamy)**

tem of interaction of surface water and groundwater is very dynamic.

### STREAMS AND POLLUTION

This interaction of surface water and groundwater explains how polluted groundwater may pollute a stream, or vice versa. A pollutant spill from a tank or chemical plant produces a plume that spreads away from the source in the direction of groundwater flow. If a stream is effluent, the pollutant will enter the stream with the groundwater. Leaky and overflowing septic systems cause special problems in this interaction. The closer the source of pollutant is to the stream, the more the stream will be polluted because the aquifer will tend to filter the pollutant. This addition of pollutant to a stream from groundwater may significantly degrade the quality of surface water along its length and causes special problems in industrial areas. Even if there is a community effort to clean and reduce pollution in the river, it can remain significantly impacted.

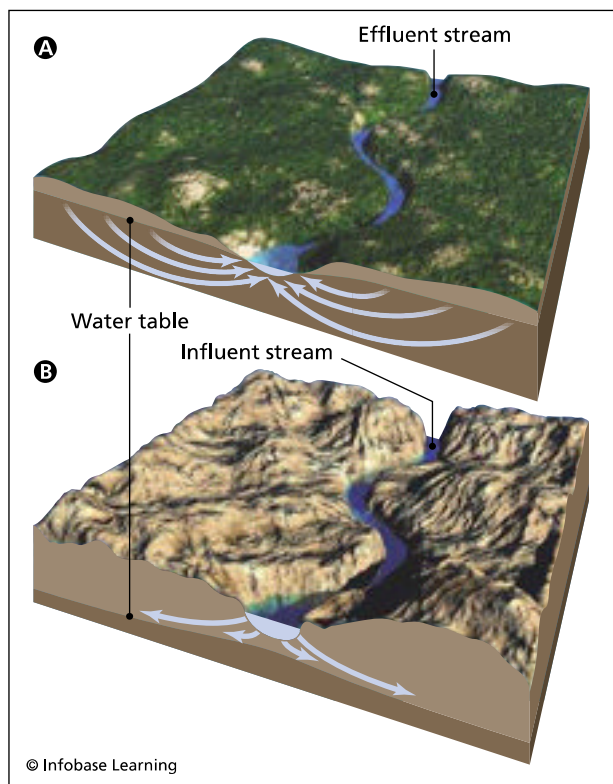
Polluted influent streams may also introduce pollutants into the groundwater system but not as frequently. The typical long travel distance through the

vadose zone to the water table will significantly filter the infiltrating water. On the other hand, many pollutants float on water, especially if they are hydrocarbon derivatives (light nonaqueous-phase liquids [LNAPLs]). Water from influent streams infiltrates the bed of the stream, thus removing cleaner water and leaving the more polluted water in the stream. In this case, the stream becomes more polluted along its length even if there is no apparent source for the pollution. This can only occur if the stream is slow and calm because turbulent flow keeps the pollutant well mixed into the stream water. In cases of dense pollutants (DNAPLs), however, groundwater may be easily polluted by stream water because the pollutant preferentially infiltrates the bed. This situation is even more dependent on stream velocity because very slow flows are required to maintain stratification of the water.

*See also* AQUIFER; GROUNDWATER; SOIL; STREAMS; WATER POLLUTION.

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**Block diagrams showing an effluent stream (A) in which groundwater feeds a stream and an influent stream (B) in which the stream water feeds the groundwater system**

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**inorganic pollutants** There are two basic divisions of industrial pollutants, organic and inorganic. Organic pollutants are linked to some kind of past or present biologic activity, or they are synthesized in a laboratory. They must include a bonding configuration that includes carbon and hydrogen but almost always includes oxygen, as well. These molecules may include other elements such as chlorine and bromine, but they are limited. These medium- to long-chain organic molecules can be broken into safer short-chain organic molecules and/or water and carbon dioxide, none of which bears any resemblance to the original pollutant. Organic pollutants actually serve as food for microorganisms in many

cases, supplying carbon for energy. The main elements in organic pollutants—carbon, hydrogen, and oxygen—are the basic building blocks of all life and are, therefore, in everything living.

In sharp contrast, inorganic pollutants are composed of elements that cannot be converted into anything else. They are naturally occurring and were part of the original components of the Earth. It is only the concentrating of them or combining of them with other elements into compounds that makes them dangerous. If organic pollutants are released into the soil, water, or even air, they will eventually be converted into other simple and common compounds. Inorganic pollutants will remain as they are until they are removed; that means that they could be there literally forever. Many inorganic pollutants are enigmatic in that trace amounts of them are nutrients that are necessary to life but excessive amounts can be highly toxic. As nutrients, they are commonly called minerals and can be seen on the labels of most multivitamins. In fact, they occur in virtually all foods. It is not only the quantity that separates nutrients from toxins but also their valence state. Oxidation, or reduction, of the inorganic element in chemical complexes can determine their toxicity. In general, water-soluble compounds are less toxic. For example, hexavalent (+6) chromium is very toxic, whereas trivalent (+3) chromium is far less toxic and even included in vitamins.

Although numerous subdivisions can be made for inorganic pollutants, for this discussion, they will be limited to heavy metals, nonmetals, radioactive elements, and miscellaneous inorganic pollutants.

### HEAVY METALS

Heavy metal pollutants include all of the metallic elements that are considered to be potentially dangerous. Originally, the term applied to metals with density greater than 6.0 g/mL, but this reference is less accepted than it once was. The most dangerous of the heavy metals are arsenic, cadmium, chromium, lead, mercury, nickel, and selenium, but other metals such as antimony, copper, molybdenum, tin, titanium, and zinc may also be dangerous at higher concentrations. Even metals that normally do not fall in the toxic category such as aluminum, iron, and magnesium can be dangerous at high enough dosage. Exposure to most heavy metals occurs only at mines and contaminated industrial sites and especially inactive sites. Soils in these areas require active remediation and can cause a significant threat to public health if not corrected properly.

The most dangerous and widespread of the heavy metals is lead. Its use was so widespread during the



industrial age up until the late 1970s that virtually everyone was exposed to it in unhealthy doses. It was in gasoline and consequently automobile exhaust, in all oil-based paint, and in plumbing everywhere in the United States. Although bans have reduced its current usage to that of many of the other heavy metals, it is still present in almost all homes built before 1970 and in all soils around those houses, as well as along the sides of roads built before that time. Peeling paint in old houses is still a significant threat to public health. Considering that lead accumulates in the body and decreases mental capacity, the cost to society of having used lead so freely may be unimaginable.

The next major threat is from mercury. In addition to being used in wool felt production, it was widely used in latex paint for many years before that use was also banned. It is still released into the air from older coal-fired power plants. The public exposure to mercury may have also been significant, and it too accumulates. Mercury released and left in the environment can pose another threat if it becomes methylated by biologic action or by industrial processes. Methylated mercury is very dangerous. One drop of dimethyl mercury, for example, can kill a person. Chromium poses similar problems with extensive use as a coating for less resistant metals and conversion to a dangerous form, hexavalent chromium, by biologic activity.

### NONMETAL POLLUTANTS

There are many more nonmetal inorganic pollutants than metals. Most are not as poisonous as the heavy metals, but many are far more widespread. Sulfur and nitrogen, for example, are major components of air pollution as oxides. Sulfur dioxide and nitrogen dioxide convert to sulfuric acid and nitric acid, respectively, when combined with water and make acid precipitation. Fallout of airborne nitrogen to the surface and open water also acts as a fertilizer that drives eutrophication in freshwater and dead zones in ocean waters. Phosphorus, another nonmetal pollutant, can also act as a fertilizer and contribute to eutrophication. It was removed from laundry detergents several years ago for this reason. Other nonmetals such as barium, bromine, chlorine, and even forms such as ozone are dangerous. They too must be remediated but, because they have non-point sources, it can be difficult to do so.

### RADIOACTIVE POLLUTANTS

There are several types of radioactive pollutants, both natural and human made. There are natu-

rally occurring radioactive elements in all soil and rocks. In low concentrations, they are not considered to cause problems. If they become concentrated by natural or anthropogenic processes, however, they can be quite dangerous. The most well-known of the radioactive pollutants is radon. This radioactive gas is inert and cannot be filtered. It can infiltrate any building or home through openings in the subsurface walls and floors or through the water supply. Radon continues to decay while in indoor air and even inhaled air until it changes into polonium, which is a reactive solid that decays very quickly. If the polonium adheres to lung tissue, it can cause mutations that could lead to lung cancer. The U.S. Environmental Protection Agency estimates that about 25,000 people die each year from exposure to radon, making it the worst environmental hazard. Radium is also naturally occurring and can occur in high concentrations anywhere there are concentrations of its parent uranium. Radium too has been linked to cancer.

When the first atomic bomb was tested in the Nevada desert in 1945, it ushered in a new age of human-generated environmental radioactivity. The first devices used fission processes, which required concentrated uranium or plutonium and released them to the atmosphere upon detonation. Later, fusion-type devices, or hydrogen bombs, did not produce significant radioactive fallout from the fusion reaction, but a fission device was required as a starter for it. The fusion explosion obliterated the fission products and by-products and delivered them as radioactive fallout. The regular testing of nuclear devices during the 1950s and 1960s during the cold war generated fallout all over the world. This testing eventually led to treaties to protect public health. Before this could happen, however, some 2,000 nuclear tests were staged. In addition to the uranium and polonium, common fallout included tritium and cobalt.

Emissions from nuclear blasts and nuclear power plant disasters, as well as the waste generated by these two sources, are considered high-level nuclear waste, which must be handled very carefully and stored. There is also low-level radioactive waste from medical procedures and certain industrial processes. It must be disposed of carefully, as well, but the constraints are not as stringent.

### MISCELLANEOUS INORGANIC POLLUTANTS

There are several inorganic pollutants that are not dangerous because of their chemistry but rather their physical form. The most infamous of these is asbestos. Asbestiform minerals, or asbestos, is a minute



grain of certain types of minerals that have a very long and thin aspect ratio. The mineral fragments are inhaled and penetrate the lung tissue, where they act as an irritant. This irritation can cause scarring of the lung, which is called asbestosis, or even a form of lung cancer that is specific to asbestos exposure, called mesothelioma. This disease results only from exposure to amphibole asbestos such as crocidolite, which is a very minor component of most asbestos. The most common type of asbestos is chrysotile, which has never been shown to cause cancer.

Silica dust like that used for sand blasting can also be inhaled and scar the lung tissue. This disease is called silicosis and can severely reduce lung function. Inhaled fibers from fiberglass insulation can also cause silicosis. Even inhaling sawdust is dangerous primarily because of the lung irritation it can cause. It, however, is an organic pollutant.

See also AIR POLLUTANTS AND REGULATION; ARSENIC; ASBESTOS; CADMIUM; CHROMIUM; COBALT; INDOOR AIR POLLUTION; LEAD; MERCURY; NICKEL; RADIOACTIVE WASTE; RADIUM; RADON; SELENIUM; ZINC.

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**in situ groundwater remediation** Technologies related to the remediation of groundwater can be divided into two categories, those that require the groundwater be extracted and taken to the surface for treatment (ex situ) and those that operate in place within the subsurface (in situ). Each has advantages and disadvantages, and the selection of one technology over another is largely dependent on such factors as contaminant type, site conditions, and the

objectives and costs of the remedial program. This description examines in situ technologies for the cleanup of contaminated groundwater.

For ex situ technologies to be effective, contaminated groundwater must be recovered or removed (pumped out) from the water-bearing zone in a way that provides a steady and reliable flow to the treatment system. Ex situ methods take the groundwater and dissolved contaminants to the treatment system. In situ groundwater remedial technologies describe or define a treatment process whereby removal of the contaminated groundwater from the aquifer, or water-bearing zone, is not necessary. Instead, the introduction and dispersal of treatment materials into the aquifer, or water-bearing zone, clean up the contaminant. Essentially, in situ technologies are designed to take the treatment method to the contaminant.

In situ methods often are preferred by regulatory agencies because they usually do not generate wastes that require further treatment or land-based disposal. Wastes are primarily sludge from wastewater treatment plants. They also tend to be less disruptive to existing land uses, are less expensive and safer to implement, and are more readily accepted by the public. They are the best choice if the contaminant mass is present over a large area or if the source of the contamination cannot be addressed by using conventional excavation techniques, for example, if it is under a building. In situ technologies, however, require more preconstruction design information, and using them can be difficult if subsurface conditions are not well characterized or behave differently than anticipated.

There are two basic types of in situ groundwater remediation technologies, those using physiochemical processes and those using biological processes. Each has its own set of advantages and disadvantages, but all are only as effective as the information upon which they have been designed.

#### HYDROFRACTURING AND PNEUMATIC FRACTURING

With ex situ technologies, there are a number of ways to capture the groundwater and get it to the treatment system. The objective of in situ methods is to rely on the naturally occurring patterns of groundwater flow to ensure an even and uniform dispersal of the treatment medium being added to the aquifer or water-bearing zone. The problem is that subsurface conditions often vary widely, especially over large areas, and groundwater flow patterns may have to be enhanced to ensure that the treatment medium has adequate access to all areas of the aquifer where contamination is present.

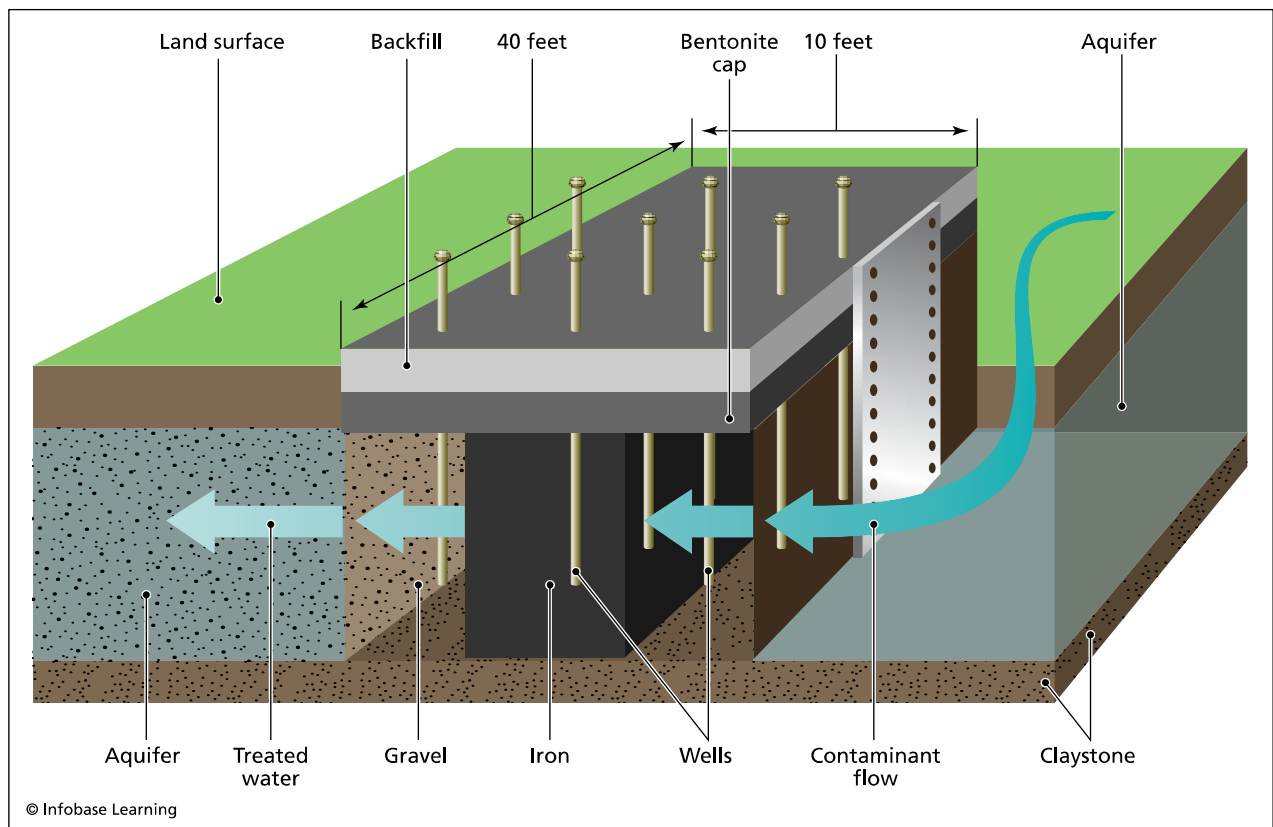
Hydrofracturing is a technique that, when properly applied, can greatly expand the ability of a treatment medium to interact with the contaminant. Developed primarily to enhance recovery from low- or slow-producing oil wells, hydrofracturing, or “hydrofracing,” is used in environmental applications if subsurface soil or bedrock conditions do not produce acceptable groundwater flow. Hydrofracturing expands or enlarges existing flow pathways or creates new ones via blast-enhanced fracturing, or pneumatic fracturing.

At sites where contaminated groundwater is present in bedrock fractures and cracks, blast-enhanced fracturing is the preferred method of hydrofracturing. Boreholes are drilled into the rock and then packed with explosives. Once explosives are detonated, the resulting expansion opens up existing fractures in the bedrock and creates new fractures and open spaces for the groundwater and treatment medium to flow through and mix with the contaminants.

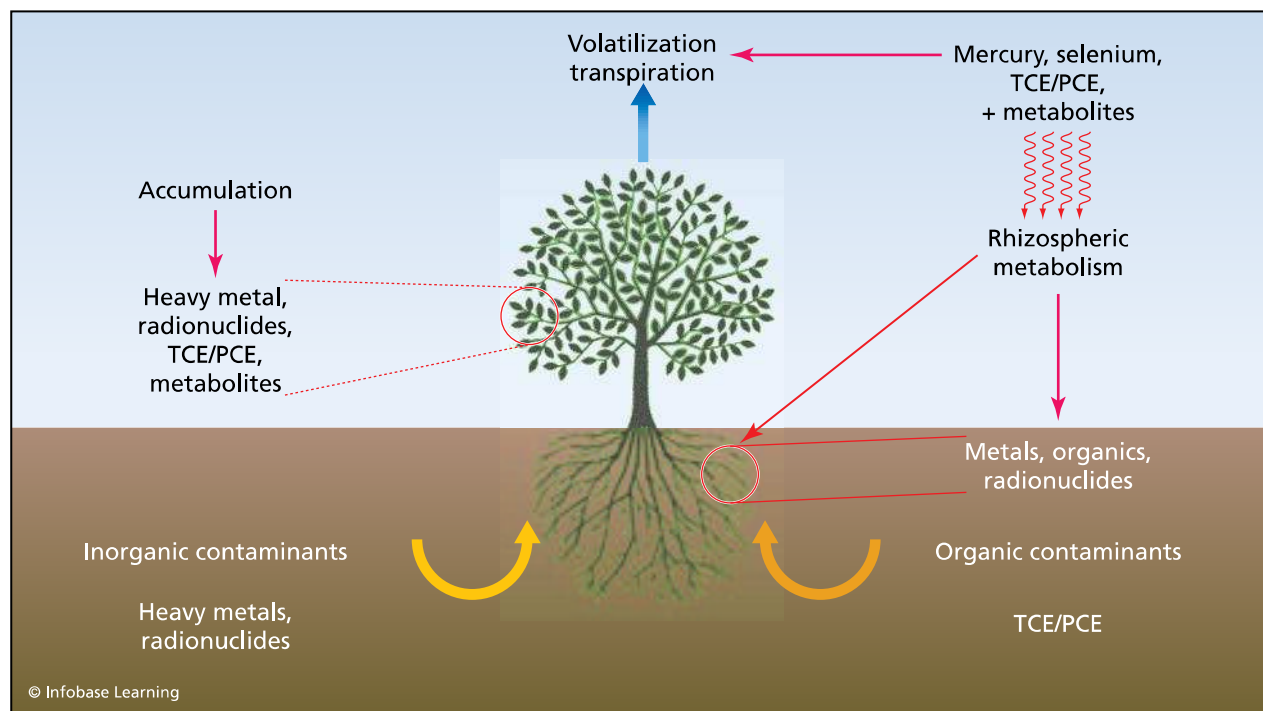
In pneumatic fracturing, boreholes are drilled through the contaminated zone and short (about two-foot- [0.6-m-] long) sections are quickly pressurized by 20-second bursts of compressed air. This

breaks up an area around the borehole. Inflatable packers, rubber balloonlike devices, are used to separate the zones within the borehole being fractured. The packers are lowered into the borehole and inflated to form a secure seal to contain the energy from the charge of pressurized air or water. The charge is directed outward or laterally into the formation being fractured. The process is repeated throughout the contaminated zone. A slurry of sand and a thickening agent, such as guar gum, are sometimes added to the compressed air that is injected into the borehole. An enzyme then is pumped into the borehole that dissolves the guar gum into a thin fluid, which is removed, leaving the sand grains to hold open the new fractures.

Care must be exercised when deciding whether or not to use hydrofracturing. In the subsurface it is largely an uncontrolled process, and the additional breaks it creates in the water-bearing formation can provide new contaminant migration pathways. The uneven distribution of fractures can still leave zones of low hydraulic conductivity even after hydrofracturing is completed. A thorough understanding of underground utility lines is also necessary in order to prevent unplanned service disruptions.



**Block diagram showing contaminated groundwater flowing through a permeable reactive barrier (PRB) containing metallic iron that reacts with and neutralizes the organic solvents, thereby remediating the water**



**Schematic flowchart illustration of how phytoremediation processes remove contaminants**

### DIRECTIONAL WELLS

Another way to enhance or improve the ability of a treatment medium to interact with the contaminant mass is through the use of directional wells. Since the late 1980s, directional drilling has been used at sites to assist in the remediation of contaminated soil and groundwater. Typical wells are vertical; they begin at the surface and extend straight down until they intersect the water table. They are drilled using a bit mounted on the end of a rigid metal pipe that is driven by a gear assembly mounted on the body of a truck or trailer. Directional drilling, originally developed for the oil industry, allows the drill bit to be routed or maneuvered to an angle from 90° to almost 180°. This allows a well to be installed in which the treatment medium can be introduced or injected directly into the contaminant mass, even if it is under a building or roadway or spread out over a large area. This type of well also is more consistent with aquifer flow patterns, as groundwater tends to move faster laterally than vertically.

There are two ways to install directional wells: trenching and drilling. To install a trenched horizontal well, a ditch or furrow is excavated from the surface to the top of the contaminant zone or water table using a backhoe, excavator, or trencher. The well screen is placed in the trench, surrounded by a layer of coarse gravel. Sometimes, the well screen is wrapped with a filter fabric to prevent clogging

of the screen by silt and clay. The remainder of the trench is backfilled to a usable grade or level with the soil removed from the trench, or clean fill is taken onto the site. Installation of parallel trenched wells at varying depths is effective at forming a high hydraulic conductivity treatment zone, where remedial additives and treatment medium can be introduced quickly to the contaminated groundwater as it migrates past the trenches.

To install a directional well, a special drilling rig is needed. For this type of installation, the borehole is started at a steep angle (45° or more) that gradually flattens to horizontal with depth. Sensors near the tip of the bit send information back to a control panel on the drilling rig that allows the operators to change the angle, speed, depth, and direction of drilling. Progress is carefully monitored, and the direction, depth, and angle of the borehole are steered or adjusted around subsurface obstructions such as buried utility lines to ensure complete contact with the contaminant mass. Although wells installed with directional drilling generally have narrow diameters, they can be constructed much deeper (40–50 feet [12.2–15.3 m] below the surface) than trenched wells. If a directionally drilled borehole enters and then exits the subsurface, it is called a continuous, or double-end, completion. Wells are easier to complete in these types of boreholes because reaming tools and well screens can be pulled backward from the

opposite ends. Single-end completion, or blind, holes are those where the drill bit enters and exits the subsurface from the same place.

Directional wells are more expensive to install than vertical wells, but because they are able to access the contaminant mass more efficiently, fewer wells usually are required to deliver the treatment. Directional wells have limitations. The depth to which they can be installed is fairly shallow, either by trenching or directional drilling, usually limited to about 100 feet (30.5 m) in depth. They are also not suitable for use in areas where the depth to the top of the water table has large variations, either seasonally or with tidal influences.

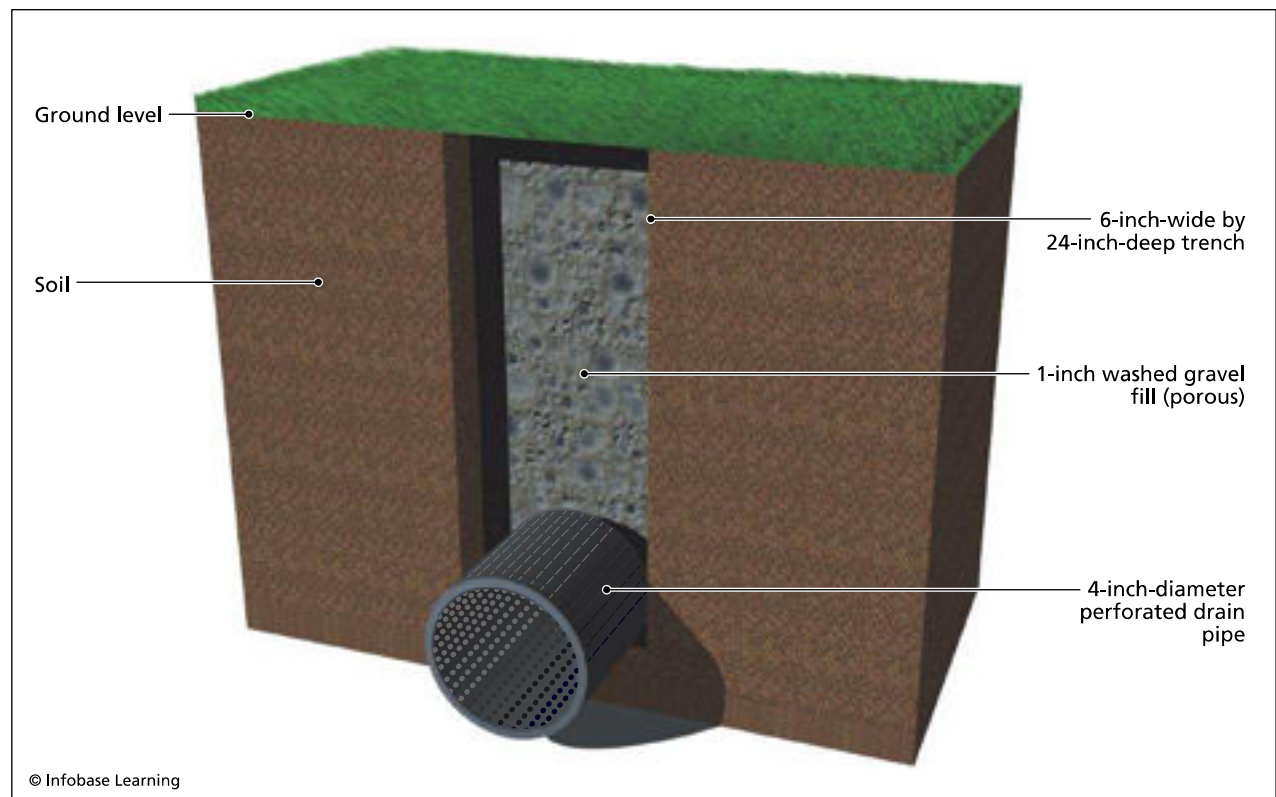
### PHYSIOCHEMICAL METHODS: DUAL-PHASE EXTRACTION

Some in situ technologies use chemical and physical processes operating on a molecular level to extract, transform, or reorganize the contaminants into less harmful substances or substances that are easier to collect and manage. These technologies can be broadly characterized as physiochemical methods.

Although it does not meet the strict definition of an in situ technology, dual-phase extraction (DPE) is

typically classified as such because it does not involve soil excavation. DPE removes from the subsurface both liquid separate, or floating “free,” contaminant product and/or impacted groundwater and gaseous contamination. There are two basic types of DPE systems, single-pump and multipump. Single-pump systems use a large suction pump to draw both liquids and vapors from the aquifer into an extraction tube or well. From there, the combined vapor-liquid waste is sent to a treatment system. Multipump systems use separate pumps to remove groundwater and/or free product and vapors for collection and treatment at the surface. DPE systems evolved as soil vapor extraction began to be combined with groundwater pump and treat systems to maximize withdrawal rates and speed the remedial process.

As the groundwater table is lowered, additional contaminated soil areas are exposed so contaminants are removed from both above and below the water table. An added benefit of DPE is that it introduces air to the subsurface and encourages bacterial degradation of contaminants, similarly to bioventing. DPE also is called multiphase extraction or vacuum-enhanced extraction and has a well-demonstrated record of proven performance at numerous hazardous waste sites.



Block diagram illustrating a shallow French drain or interceptor trench



### IN-WELL AIR STRIPPING

For in-well air stripping or in-well vapor extraction, in situ vapor stripping, recirculating wells to work efficiently, bubbles, and circles are needed. Although several commercial variations of this technology have been developed, they all introduce air into a circular flowing pattern of groundwater entering a well. The process takes place in three steps:

**Step 1.** A specially designed well (sometimes called a circulating well) is installed in the contaminated groundwater. This well has an upper and a lower casing separated by a barrier, such as a metal plate, rubber seal (packer), or cement/bentonite grout. This barrier restricts water flow direction in the well to in through the lower screen and out through the upper screen. The lower screen is installed below the water table, whereas the upper screen is installed across or above the top of the water table.

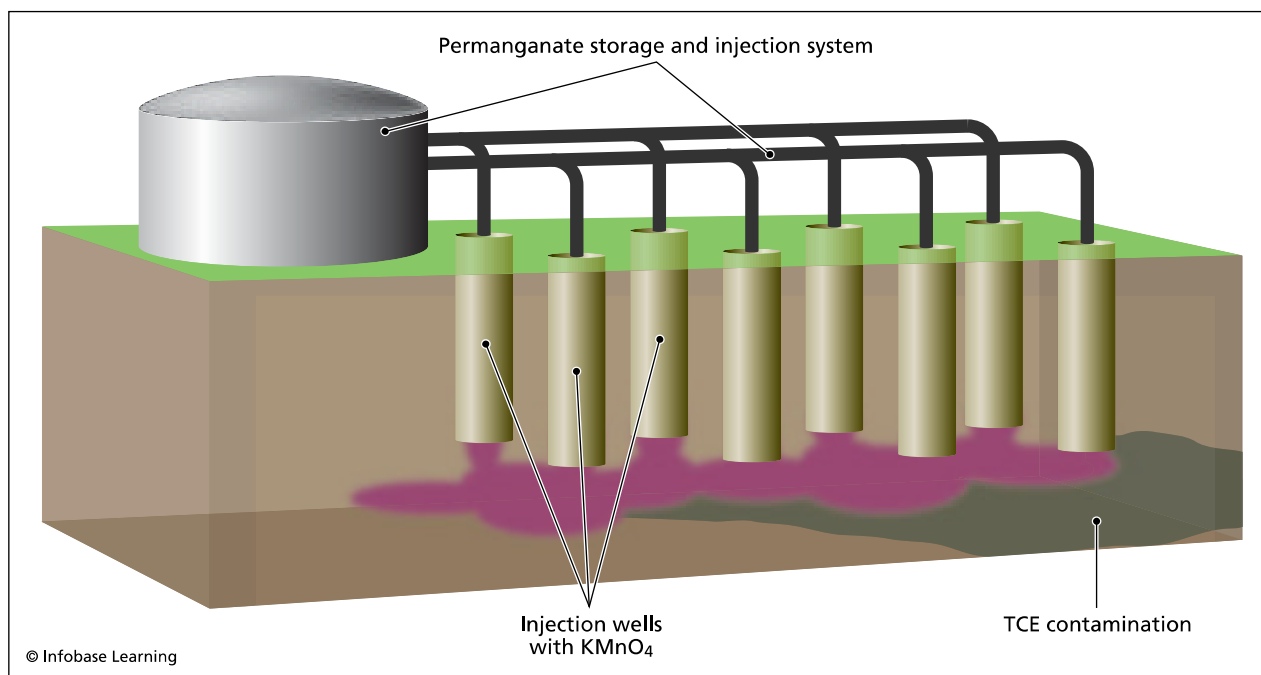
**Step 2.** Air or an inert gas such as nitrogen is introduced near the bottom of the lower screen and bubbled up through the groundwater. The presence of these bubbles decreases the density of the groundwater, and it rises, moving from the lower portion of the well, past the hydraulic barrier, and into the upper portion of the well. These bubbles also serve to strip off VOCs present in the groundwater. Resulting off-gases are collected by

a suction tube and transferred to an aboveground treatment system.

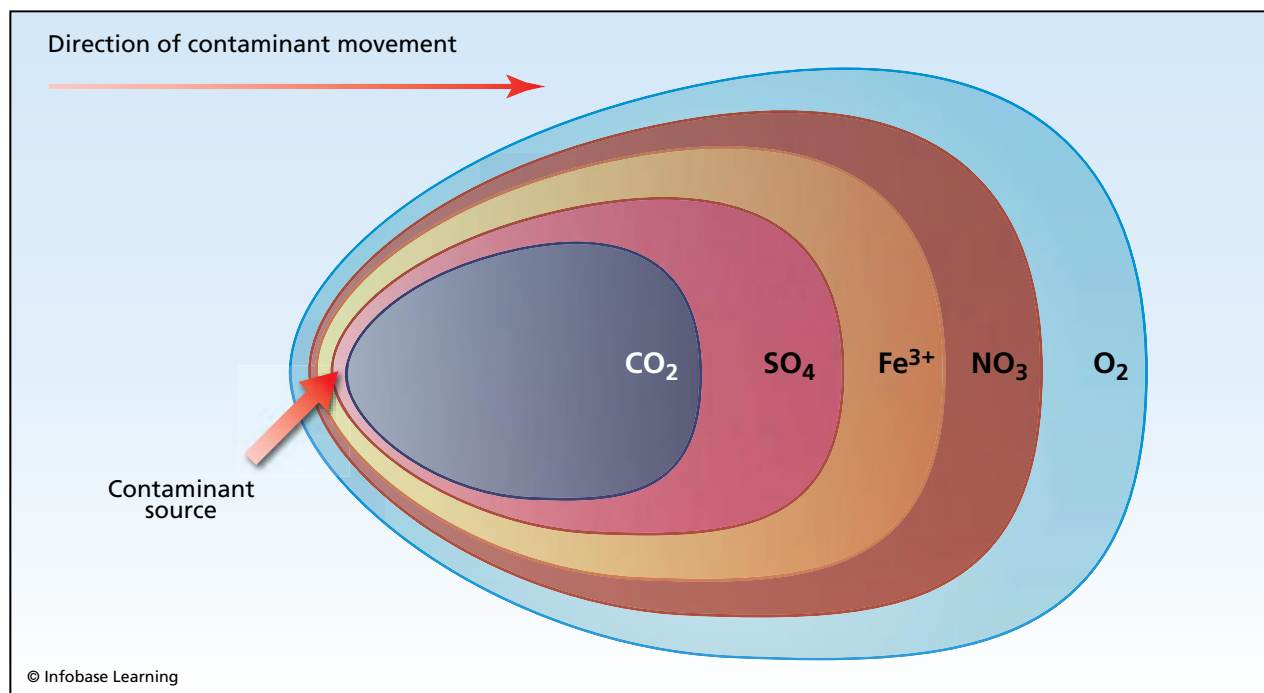
**Step 3.** Once the groundwater enters the upper casing of the well, it is allowed to infiltrate or reenter the contaminant zone to help flush out residual concentrations of VOCs that may be present in the soil or aquifer. This pattern of rising and infiltrating groundwater forms a circulation cell or zone around the well, which continues until VOCs detected in the groundwater meet regulations. The introduction of air also can help oxygenate the groundwater and enhance bacterial degradation of contaminants.

The area around the recirculating well through which groundwater flows in a circular pattern is called the circulating well's area of influence. Depending on subsurface conditions, these areas of influence can extend tens to hundreds of feet from the circulating well. Often, more than one circulating well is installed so that their areas of influence overlap and form a hydraulic barrier to control off-site migration of contaminated groundwater. The in-well stripping method can be modified by introducing chemical additives such as nitrate into the circulating well to support or enhance bioremediation.

In-well air stripping works best on organic compounds that are volatile and do not adhere well to soil. These types of contaminants include halo-



**Illustration showing a storage tank of potassium permanganate attached to an injection well system built to remediate a trichloroethylene (TCE) release**



**Illustration of a subsurface map view of electron acceptor utilization zones in a dissolved contaminant plume with the operative chemicals in each zone**

generated and nonhalogenated volatile organic compounds (VOCs) and nonhalogenated semivolatile organic compounds (SVOCs). Site conditions, however, can greatly influence the effectiveness of this technology. Vertical changes in soil and sediment types with depth interfere with the ability of the groundwater to flow evenly into the circulating well. The introduction of air may result in the oxidation (precipitation) of iron, magnesium, or other metals that may build up and foul the system. Aquifers that have water tables close to the surface may not have enough of an unsaturated zone to allow a circulating pattern to be established.

Despite these drawbacks, circulating wells are an attractive remedial technique. Operational costs related to pumping are usually lower because groundwater does not have to be taken to the surface for treatment. State and federal permitting requirements are usually minimal because the captured groundwater is not discharged to a surface water body or sewer.

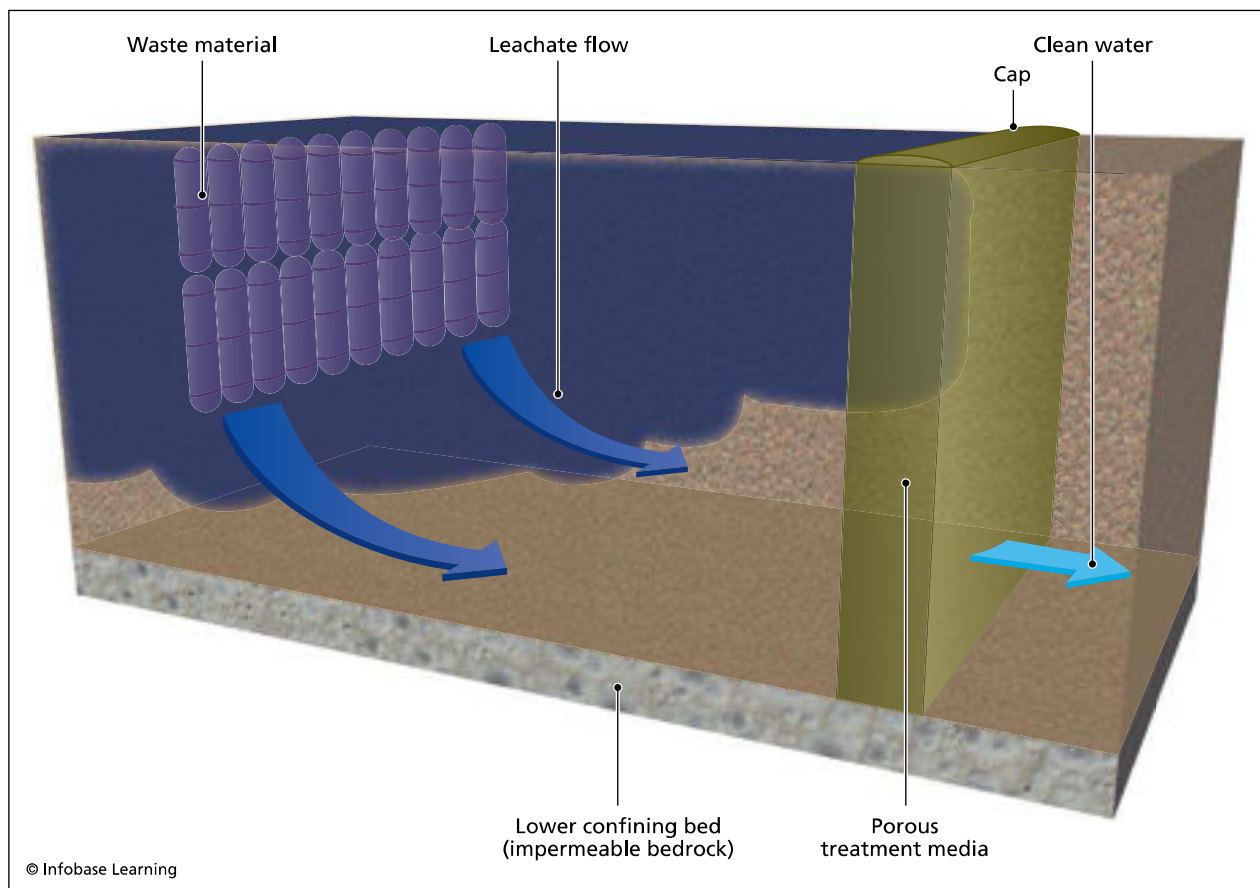
### STEAM EXTRACTION

Although expensive, one of the most effective ways to remove contaminants from the subsurface is with steam or hot water extraction. Its technological basis is quite simple: Steam is injected into the contaminant mass and vaporizes volatile and semivolatile contaminants. A vacuum extraction system

then is used to recover the vaporized components to an aboveground treatment system for distillation and recovery, incineration, or circulation through a filter.

In the most basic design, the injection wells are placed in the center of the contaminant mass, with the extraction wells positioned along the edges. Steam is injected either above or below the water table depending upon the location of the contamination at a pressure greater than the hydraulic pressure present in the aquifer. At the same time, the extraction wells are activated, to encourage the flow of volatilized contaminants toward them. As the steam front advances through the subsurface, it pushes the contamination in front of it, toward the extraction wells. Soil temperature probes are installed between the injection and extraction wells and, when the area between the two reaches the steam temperature, the flow of steam is reduced to the amount needed only to maintain the temperature in the soil. Another way to detect that the correct soil temperature has been reached is that steam starts to appear in the extraction wells. Many VOCs and SVOCs have boiling points much lower than that of water, and remediation (volatilization) is often rapid.

In some commercial systems, hot water is used in place of steam. The hot water flushes the contaminants into the extraction wells, where they are separated



**Diagram showing leachate flowing from a waste material source and through a porous treatment medium that removes the contaminant as the water filters through, thereby cleaning the groundwater**

and collected for off-site disposal. The water is then treated and either discharged or reinjected.

As with hydrofracturing, this technology has been adapted from the oil fields, where steam injection has been used for years to reduce oil viscosity and improve the yield of older wells. In environmental applications, steam extraction most commonly is used as an enhancement or supplemental technology in combination with the primary remedial system. Steam makes contaminants more mobile and recoverable for pump-and-treat and soil-vapor extraction systems. The addition of steam also encourages bioremediation and can greatly improve the performance of bioventing and bioslurping systems. For steam extraction to be considered a viable remedial alternative, the soil must be permeable enough to allow for its flow through the subsurface, and the contaminants should be relatively volatile.

### AIR SPARGING

Air sparging injects air directly into the contaminated groundwater. As the air moves through the

aquifer, it volatilizes contaminants, acting essentially as a belowground air stripping system. Contaminants bubble out of the aquifer and into the vadose zone, where they are collected by a soil-vapor extraction system. This combination of technologies—air sparging creating positive pressure in the subsurface and soil-vapor extraction creating a corresponding negative pressure—is one of the most common remedial techniques used to treat groundwater and soil contaminated with VOCs.

As with other in situ approaches, the increased flow of air also encourages bacteria to degrade the contamination. Sometimes gaseous bacterial nutrients (propane) or chemical oxidants (ozone) are used in sparging systems to help destroy or break up the contaminants in place, reducing the need for off-gas treatment. Air sparging systems are required to operate at flow rates so that sufficient air enters the aquifer to react with the contaminants but does not cause uncontrolled discharges to the atmosphere or into the basement of a building.

The effectiveness of air sparging is dependent on the ability of the system to push air through the

subsurface. If soil conditions are variable, airflow may not be uniform enough to reach all of the contaminated zones. The deeper the contamination, and the less permeable the soil, the more difficult it will be for air sparging to be effective. Air sparging only works on those VOCs that are easily volatilized.

### PERMEABLE REACTIVE TREATMENT WALL

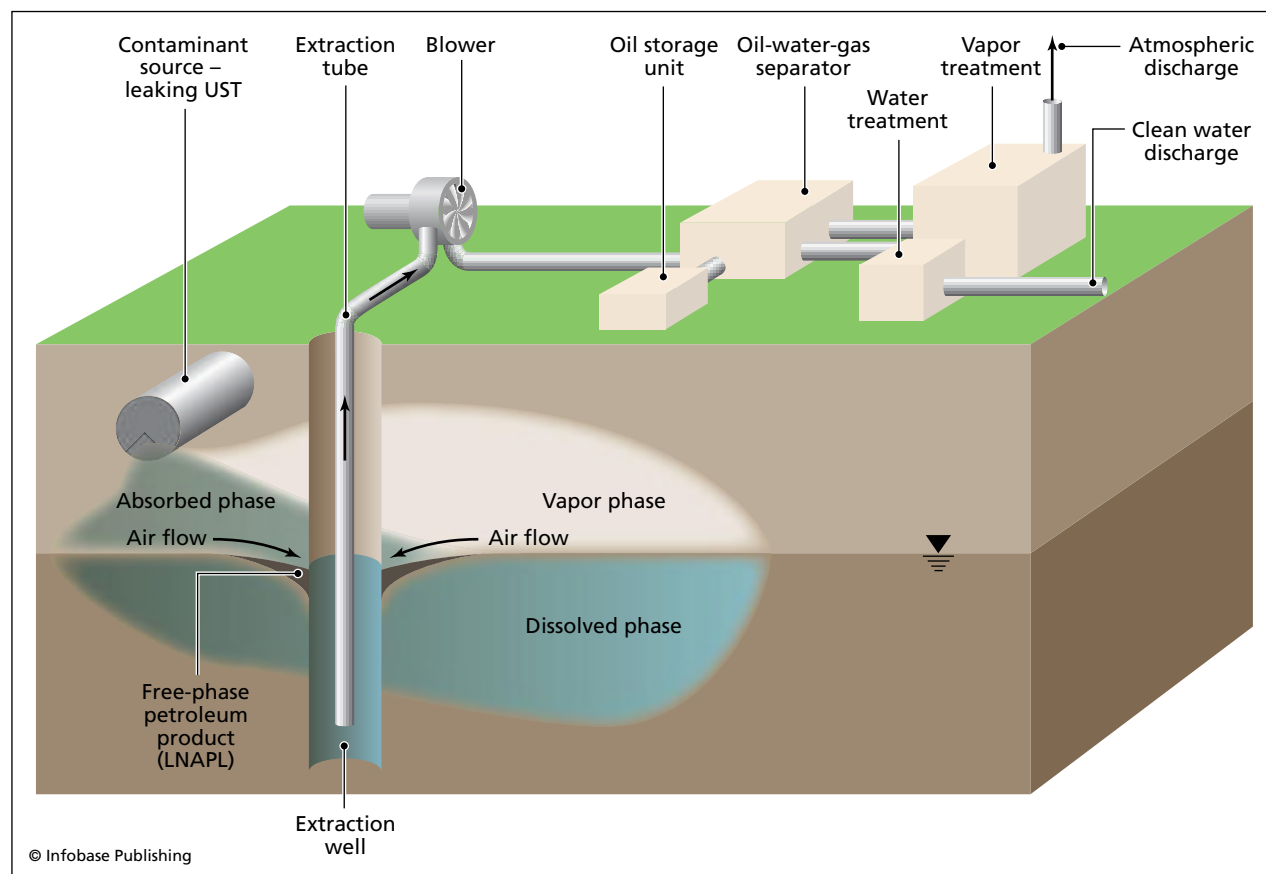
One way to control the flow or movement of groundwater is through the installation of a slurry or cut-off wall where a thick, impermeable wall of clay is installed below the surface to prevent migration of contaminated groundwater off a site. If a permeable substance that allows the contaminated groundwater to flow through it but neutralizes or absorbs the contaminant as it passes is used instead, it can be an effective remedial tool. This tool is a permeable reactive treatment wall or barrier. A wall or curtain of a granulated metal or other special compound is installed in the path of the migrating contamination. As the groundwater passes through this material, the

contaminant reacts with the material in the wall and is either absorbed or changed to a nontoxic form.

With no operational or maintenance costs or the need for expensive aboveground treatment systems, permeable reactive treatment walls can be a very cost-effective solution for groundwater contamination. As an added attraction, because of the passive nature of its operation, the affected property can remain in productive use after installation of the wall with little or no disruption to ongoing operations.

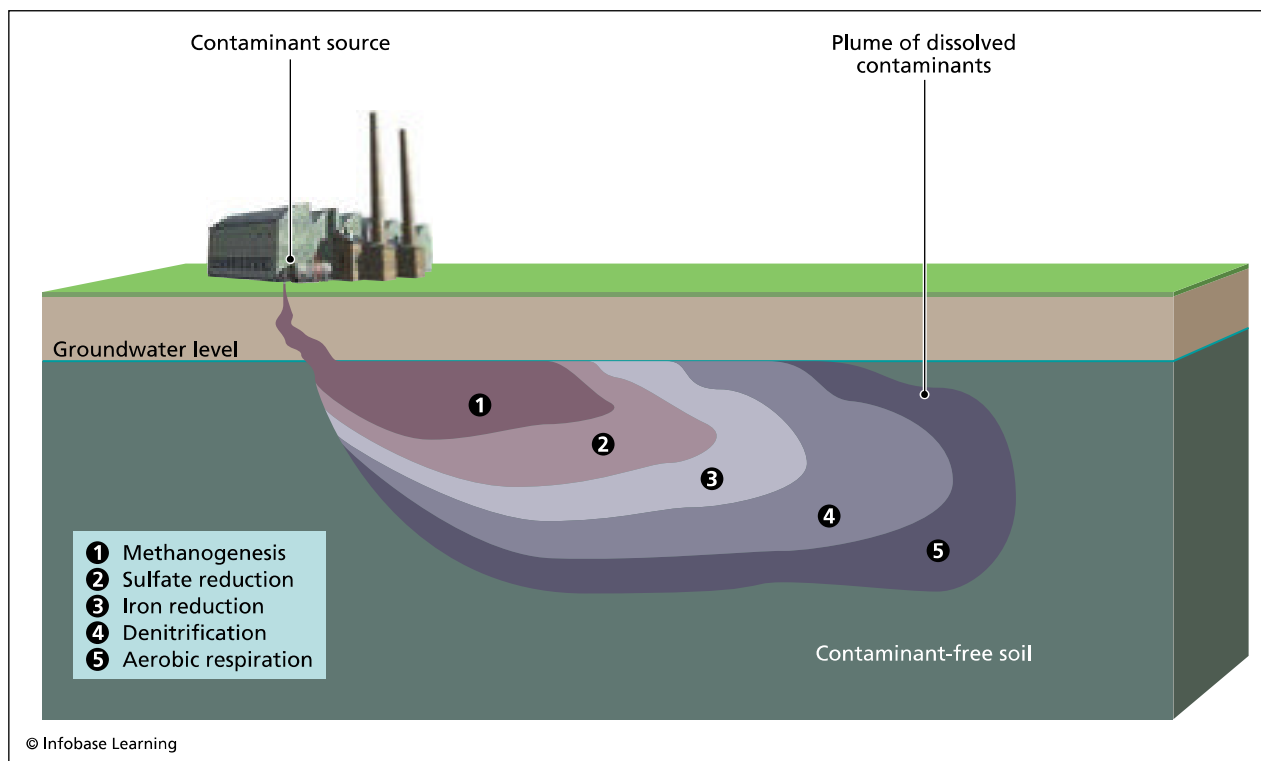
Walls are installed using a variety of methods and can be composed of several different types of treatment media; the most common include zero-valence or reactive metals, usually iron; chelators such as zeolite, which are selected for their attraction to a specific metal; and nonreactive sorbents such as powdered activated carbon; and bacteria-supporting medium of mulch or compost.

An especially effective wall configuration is called funnel-and-gate. These are used for wide groundwater plumes or when contamination is unevenly



**Block diagram showing the release of light nonaqueous phase liquid (LNAPL) from an underground storage tank (UST) into the groundwater system and the dual-phase extraction system installed to remediate it. The system cleans contaminants from both liquid and gas (vapor) drawn through an extraction well drilled into the plume.**





**Diagram showing plume of contaminant from a surface source extending down below the water table. A cross-sectional view of the plume shows the distribution of electron utilization zones.**

distributed throughout the water-bearing zone. The funnel portion of the system consists of impermeable wings of sheet piles or slurry walls that extend out from the treatment wall. These wings or funnels divert and direct the plume toward the permeable reactive zone in the treatment wall.

At some sites, walls are not constructed at all. Instead, treatment media are injected into closely spaced boreholes or wells. This approach, called barrier well injection, is used for narrow, relatively small contaminant plumes and can be installed quickly with little disruption to ongoing site activities. The treatment medium also can be reinjected as often as needed to clean up recalcitrant contamination.

Treatment media in the wall eventually degrade or become saturated with the contaminant being removed from the groundwater and must be periodically replaced. For example, the iron in a zero-valent iron wall being used for the treatment of chlorinated compounds such as trichloroethylene (TCE) or dichloroethene (DCE) is oxidized when it removes a chlorine atom from the TCE or DCE. The iron granules are dissolved by the process, but so slowly that the wall can remain effective for many years. Other limitations on the use of reactive treatment walls include changes in the permeability of the wall over time as metals precipitate or bac-

teria grow and clog up the pore spaces. If a plume is large, the size of the wall needed to treat it can become prohibitively expensive, both to install and to fill with the treatment medium. Subsurface utilities, local geologic conditions such as boulders, and the depth of the plume all increase the difficulty of installing a reactive treatment wall. Installation of walls greater than 80 feet (24.4 m) below the surface requires the use of expensive specialized trenching equipment.

### CHEMICAL OXIDATION

If contaminant concentrations in the groundwater are large, or if nonaqueous-phase liquids (NAPLs or “free product”) are found, the use of in situ chemical oxidation (ISCO) is often the remedial technology of choice. ISCO entails injection of chemical oxidants into the vadose zone and/or groundwater. These oxidants then attack the contaminants, reducing them to carbon dioxide and water if the reaction goes to completion. ISCO is most commonly used at those sites where the treatment of residual free product is necessary and/or where there are time constraints on remediation.

Oxidation occurs only in the aqueous phase, and this technology depends on the flow of groundwater

through the impacted area to deliver the oxidant to the contamination. It is preferred at sites with stratified soil with low permeability or where the contaminants are not very soluble or are difficult to treat such as ketones, alcohols, or methyl tert-butyl ether (MTBE). The most commonly used oxidants are hydrogen peroxide-based Fenton's reagent and potassium permanganate. Ozone also can oxidize organic contaminants but is not used as frequently. The most effective ISCO systems produce hydroxyl radicals. These radicals are very powerful oxidizing agents, followed closely in effectiveness by potassium or sodium permanganate.

### Peroxide

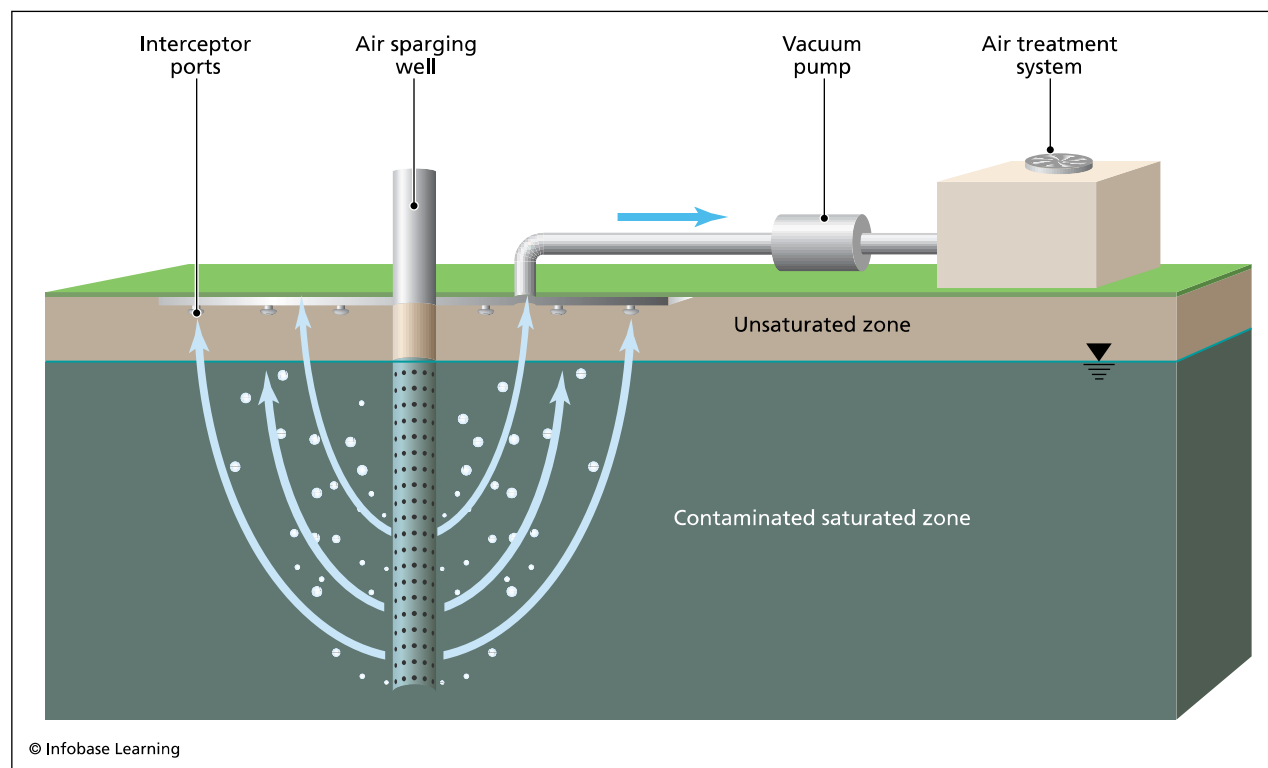
Oxidation of contaminants can be triggered by introducing liquid hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) activated, or made more aggressive, by the presence of ferrous iron ( $\text{Fe}^{2+}$ ) into the water-bearing zone. This compound, known as Fenton's reagent, produces enormous quantities of strongly reactive hydroxyl radicals ( $\text{OH}^\cdot$ ). These hydroxyl radicals rapidly oxidize and degrade organic compounds by removing their electrons and physically breaking apart the chemical bonds that hold these big, complex molecules together. Fenton's reagent works best at sites where the pH is acidic.

### Permanganate

The oxidation chemistry of permanganate in the subsurface is complicated. Although typically injected as a liquid in combination with potassium ( $\text{KMnO}_4$ ), it has also been used as salts of Na, Ca, or Mg. Naturally attracted to organic molecules with double carbon bonds, aldehydes, and hydroxyl groups, permanganate uses such mechanisms as hydroxylation, hydrolysis, and cleavage to break apart the electrical bonds holding these large molecules together. If used in the proper amount, permanganate can reduce the removal half-life of TCE and DCE in the groundwater to between 30 seconds and 18 minutes. The half-life of PCE is about four hours. Permanganate is more stable and versatile than Fenton's reagent and is, therefore, more persistent in the subsurface than peroxide and can be used to treat larger plumes.

### Ozone

The strongest of the chemical oxidants, ozone ( $\text{O}_3$ , or triatomic oxygen), is a double threat. It can oxidize organic contaminants directly by removing electrons and destabilizing the molecule. Ozone also generates free radicals (hydroxyl radicals) that break the carbon bonds that hold the organic contaminant compounds together. Another added advantage is that



**Schematic diagram of an air sparging groundwater treatment system that pumps air into the ground and removes the vaporized contaminants by air treatment**

as the ozone itself breaks down, it generates oxygen, which can aid in the bioremediation of untreated residual contamination. Ozone must be generated at the site by an ozone generator using either compressed oxygen or ambient air and is injected as a gas into the contaminant mass. A typical application rate is about 1–10 pounds (0.45–4.5 kg) of ozone to each pound (0.45 kg) of contaminant.

These types of oxidants must be injected into the contaminant, although at sites where the groundwater is moving relatively quickly, passive delivery systems may be appropriate. In slower-moving groundwater regimes, delivery of oxidant to the contaminant zones may require both injection and extraction wells. ISCO has been used to remediate VOCs, polycyclic aromatic hydrocarbons (PAHs), petroleum products, and explosive compounds.

ISCO has limitations. Some contaminants are resistant to oxidation (beryllium, for example), and the presence of naturally occurring organic matter increases the need for additional amounts of oxidants in the subsurface, greatly increasing chemical and distribution costs. ISCO oxidants are very reactive compounds and care needs to be exercised in their handling and storage. Changes in subsurface soil conditions can cause problems during injection or infusion of oxidants, and their use is not economical for large, widely dispersed, low-concentration (<5 mg/L) plumes. Also, certain metals such as

chromium, uranium, and molybdenum may not be soluble before introduction of oxidant but could be dissolved in the groundwater by this process. Finally, ISCO relies on the oxidant's having contact with the entire contaminant mass, and, as a result, the process is dependent on the efficiency of the delivery system. Insoluble metals can form as part of the oxidation reaction ( $\text{MnO}_2$  from permanganate, for example) and can plug up the soil and reduce the ability of the oxidant to interact with the contaminant mass.

### BIOLOGICAL IN SITU GROUNDWATER REMEDIATION

In situ remediation involves creating or modifying the subsurface environment to support the use of a physical or biological process that detoxifies, removes, or stabilizes a contaminant mass. The next broad category of remedial technology relies on bacterial or microbiological processes. The success of these technologies depends on their ability to create either aerobic or anaerobic conditions in the subsurface.

#### Bioslurping

Bioslurping is a combination of two remedial technologies, dual-phase extraction and bioventing, and is used to address both contaminated soil and

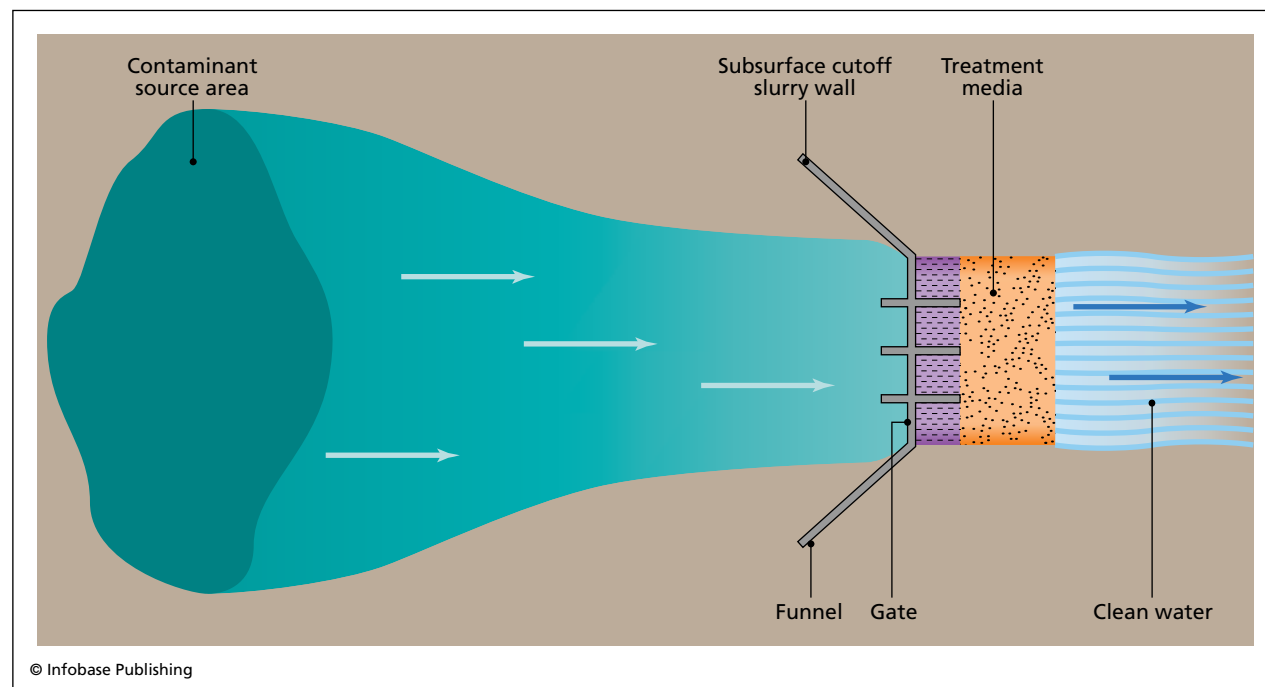
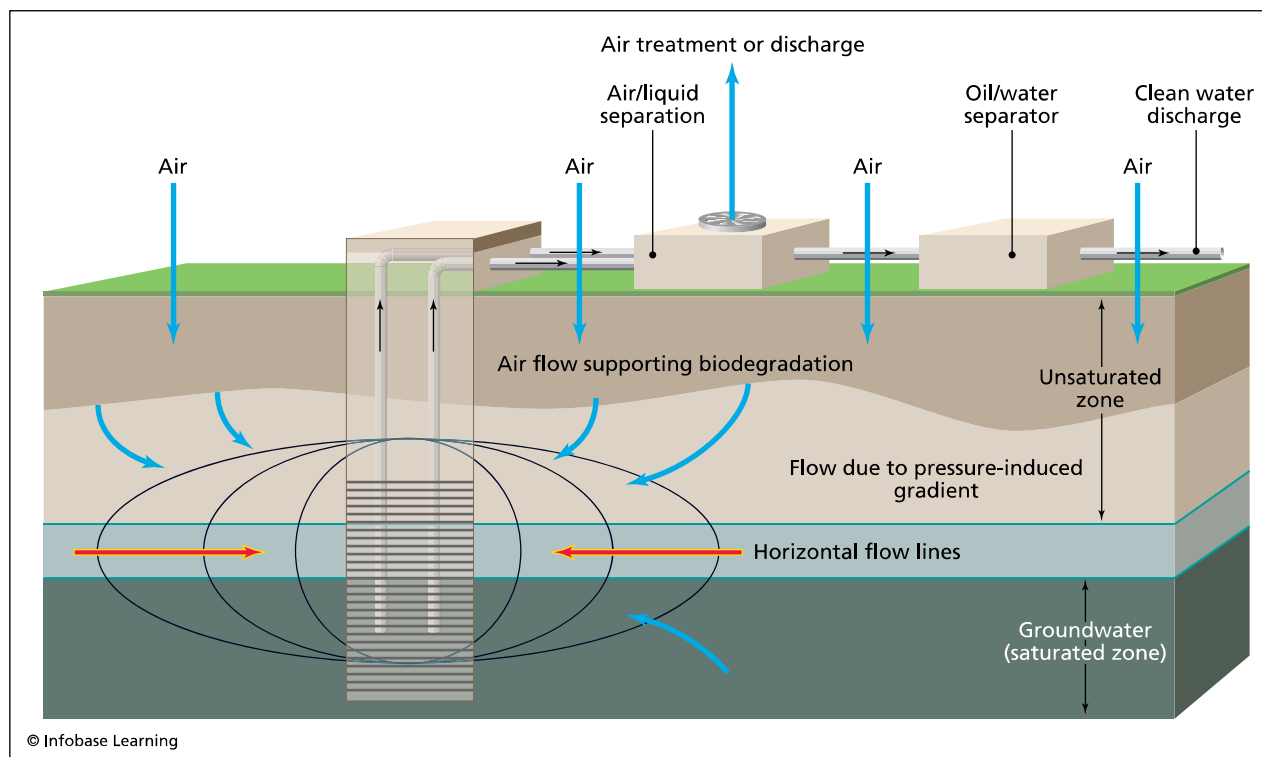


Diagram showing the subsurface map view of the release of contaminated water from a contaminant source and its collection in a funnel-and-gate groundwater treatment system



**Schematic cross-sectional diagram of a bioslurping groundwater and soil treatment system**

groundwater at the same time. It captures free product LNAPL contaminant without extracting significant amounts of groundwater.

Dual-phase extraction removes separate contaminants (LNAPLs) from the top of the water table by using pumps to draw liquid and vapors from the aquifer and vadose zone into an extraction tube. This minimizes changes in water table elevation and prevents contaminants from being spread across the soil-water table interface. As the DPE system lowers the groundwater table, soil that is normally saturated with either LNAPL or water is exposed and made accessible for treatment by bioventing.

Bioventing is an in situ remedial technology that enhances the growth of contaminant-degrading bacteria by the addition of air and sometimes nutrients into the unsaturated zone. Bioventing is an add-on component to the DPE system, and air and nutrients, as needed, are introduced as the LNAPL and groundwater are withdrawn. When no more LNAPL can be recovered, the bioslurping equipment can be easily converted to a stand-alone bioventing system to complete the remediation.

Bioslurping is most frequently used to remediate soil and groundwater impacted by petroleum hydrocarbons, especially automobile and aviation fuels. It can even be cost-effectively used at sites where the water table is more than 30 feet (9.1 m)

below the ground surface. Soil permeability is an important factor in deciding to use bioslurping. The less permeable the soil, the more difficult it is to pull out LNAPL and push in air. Other limiting factors are those that are common to any bioremedial system and include dry soil, which tends to get even dryer when air is blown through it; low temperature, which slows bacteria growth; and very high or low pH, which creates hostile growth environments for microbes. Consideration also needs to be given to how water and gases recovered by the system will be treated and discharged.

### Phytoremediation

The in situ use of plants to stabilize, detoxify, or dilute contaminated soil or groundwater is called phytoremediation. Two types of phytoremediation technologies are used exclusively to address contaminated groundwater: rhizofiltration and phytovolatilization.

### Rhizofiltration

As shallow groundwater containing dissolved contaminants migrates laterally in the subsurface, it passes through the root zone (rhizosphere) of numerous types of plants. Some of these plants have the ability to adsorb onto their roots or take up into their roots these dissolved contaminants. This is



known as rhizofiltration or phytofiltration and it can operate either abiotically or biotically.

Abiotic rhizofiltration takes place outside the plant if exudates from plant roots change local pH or redox conditions and precipitate dissolved metals out of the groundwater. Biotically mediated rhizofiltration occurs inside the plant when growth and nutrient uptake mechanisms draw dissolved contaminants from the groundwater and absorb them into their root mass.

Rhizofiltration is used when the goal of the cleanup effort is to contain and remove the contaminant from the site. Compare this to phytostabilization and phytoextraction, where the plants are left in place after concentrating and fixing the contaminants in the roots or aboveground parts of the plant. In rhizofiltration, after the contaminant saturates the plant, its roots and leaves, stems, or branches are harvested, packaged, and shipped to a waste treatment facility for final disposal. It is most commonly used at sites where groundwater is contaminated with metals such as lead, cadmium, chromium, or radionuclides such as uranium, cesium, and strontium.

Plants commonly considered for use in rhizofiltration systems are certain varieties of sunflowers and Indian mustard, both of which have demonstrated their ability to remove lead, copper, and chromium from groundwater. Plants with fast-growing root systems are preferred and seedlings are the most efficient at rapidly taking up metals with only minimal light and nutrients. Plants used in rhizofiltration are germinated in greenhouses, with their roots in water rather than soil. This tends to increase their root mass and, once they are well established, contaminated water is substituted. The plants then begin a predetermined acclimation period before they are transplanted at a contaminated site. Research is currently under way to alter plants genetically to increase their rhizofiltration ability.

Rhizofiltration is best suited for treating large, shallow contaminant plumes containing low concentrations of metals in the parts per billion (ppb) range. Plants with little surface growth are used, in order to minimize disposal costs. Rhizofiltration, as do most phytoremediation technologies, works best in climates with long growing seasons, and design consideration must be given to developing a system that prevents the transfer to or bioaccumulation of contaminants in animals.

### **Phytovolatilization**

Phytovolatilization relies on contaminant removal and transfer by withdrawing the contaminant from the groundwater and exhaling it into the atmo-

sphere. This occurs as growing plants take up water and contaminant, pass it through their vascular system into their leaves, and release it to the atmosphere. To be truly successful, phytovolatilization also alters or transforms the contaminant to a less toxic or bioavailable form. This has been demonstrated at sites where selenium is transformed to dimethyl selenide gas or organic mercury is changed to less toxic elemental mercury. After being released to the environment, many contaminants also can be further degraded by other natural processes such as sunlight-induced photodegradation.

### **Enhanced Bioremediation**

Although belowground, away from sunlight and oxygen, and at low temperature, groundwater and the soil it moves through often contain a wide variety of microbial organisms that, if properly stimulated, can be extremely effective in the degradation of many contaminants. The process of stimulating the naturally occurring bacterial population present in the subsurface through the addition of nutrients and electron acceptors is called enhanced bioremediation.

Interest in and study of groundwater microbiology have increased recently as environmental scientists and remedial engineers have begun to realize how important a tool bacterially mediated degradation of contamination can be. In the early days of bioremediation science, sampling and culturing techniques provided data that indicated the number of bacteria present in groundwater decreased with increasing depth. The prevailing wisdom was that the deeper the groundwater, the fewer bacteria it would contain, and at some depth the water would be essentially sterile. By the 1970s, testing methods had become more sophisticated, and groundwater from very deep aquifers (greater than 2,000 feet, or 610 m) was found to contain significant bacterial populations.

It is easy to identify the presence of bacteria in groundwater or most other substances using a procedure called a standard plate count, in which a 0.034-fluid-ounce (1-mL) sample of the material to be tested is spread evenly over a growth medium, most commonly agar. Originally developed from potatoes, modern agar is an extract from seaweed or algae and is used as a culture medium and a gelling agent in food. The agar is mixed with sterilized water, phosphate, nitrate, and sugar or glucose, as a carbon source, and the sample is incubated at 95°F (35°C) for 48 hours. The glass container that the agar mixture is stored in is called a plate, and different combinations of agar and nutrients can be used, depending upon the types of bacteria for which

the substance is being tested. After 48 hours, the number of bacteria that appear on the plate either as pairs, chains, clusters, or single cells are counted and reported as “colony-forming units” (CFUs) per milliliter. In the United States, most drinking water is allowed to have up to 500 CFU/mL. A widely accepted industry standard for milk is 5,000 CFU/mL.

Bacteria, and indeed all life on Earth, have similar, fundamental nutritional needs. Primarily, an energy source is needed. For plants this is the Sun; for people and other higher life-forms it is oxygen. For bacteria it can be oxygen, nitrate, or other types of inorganic compounds. Nitrogen is the second most critical nutritional component. This can be provided as nitrogen gas, which constitutes some 78 percent of the Earth’s atmosphere; or ammonia ( $\text{NH}_3$ ), nitrate, nitrite, or nitrogenous organic compounds found in proteins or nucleic acids. Carbon also is an essential nutrient and is found in carbon dioxide, methane ( $\text{CH}_4$ ), carbon monoxide, or complex organic materials such as plants and the flesh of animals. Most cells also require phosphorus, sulfur, magnesium, potassium, sodium, and calcium, some in significant amounts, others only in very small amounts. Finally, all life requires liquid water in order to live, grow, and reproduce. Water provides the pathway for nutrients to enter and waste materials to leave cells, as well as being essential to energy production. Although some resting stages of cells, such as bacterial spores, can remain dormant for an extended length of time without free water, they will eventually need it to grow or metabolize. Trace nutrients or trace metals such as iron, zinc, and cobalt are also required, albeit in very small amounts. Enzymes use these metals to help catalyze or speed up cellular functions.

The mere presence of an energy source and nutrients in the environment is not enough to drive life and growth processes. They must also be bioavailable. Broadly defined as the absorption and utilization of a nutrient or energy source, *bioavailability* is the ability of a substance to interact with living systems. The way a substance becomes bioavailable is a function of its physical or chemical state, whether it tends to be adsorbed, absorbed, bonded, or precipitated as it moves through the environment. Contaminants can be bound to soil particles because of chemical, electrostatic, or hydrophobic reactions. The strength and longevity of this bonding vary as subsurface conditions change over time. Bioavailability is dependent on whether the substance can move through a physiological barrier, such as a cell membrane, and enter a living organism. For bacteria and plants, however, bioavailability is directly

related to solubility. The substance must be dissolved in water to enter and interact with these types of organisms.

Bacteria have adapted their biochemistry of energy and nutrient use in order to survive at depth in the harsh environment of an aquifer or water-bearing zone that is dark and has little to no oxygen and little carbon. Microorganisms such as bacteria obtain energy and grow using oxidation-reduction reactions that transfer electrons from a donor (oxidizer) to an acceptor (reducer). The first step in this process occurs when an electron acceptor such as oxygen becomes available to receive or take in an electron from a donor such as spilled gasoline. Through a mechanism known as the electron transfer, electrons from the donor spilled gasoline are passed along through the bacteria’s mitochondrial membranes until they attach to a final, or terminal, electron acceptor, the oxygen.

As the electrons are passed along, a variety of cellular mechanisms use some of the energy released during their transfer to create large amounts of a compound called adenosine triphosphate (ATP). Made up of one adenosine molecule and three inorganic phosphate molecules, ATP powers the biological processes of organisms. When energy is needed for growth or for carrying out of normal biological functions, enzymes cleave off a phosphate molecule from the ATP, breaking it down into adenosine diphosphate (ADP). The breakup of the ATP molecule releases chemical and electrical energy that is used by the cell to live, grow, and reproduce. As electron acceptors or oxygen become available, ADP is converted back into ATP and stored in the cell for later use. This cycle of creation of ATP, its breakdown into ADP, and its re-formation back to ATP is called cellular respiration, and it is driven by complex biochemical mechanisms that eventually produce large amounts of ATP using an inorganic electron acceptor and the electron transport chain.

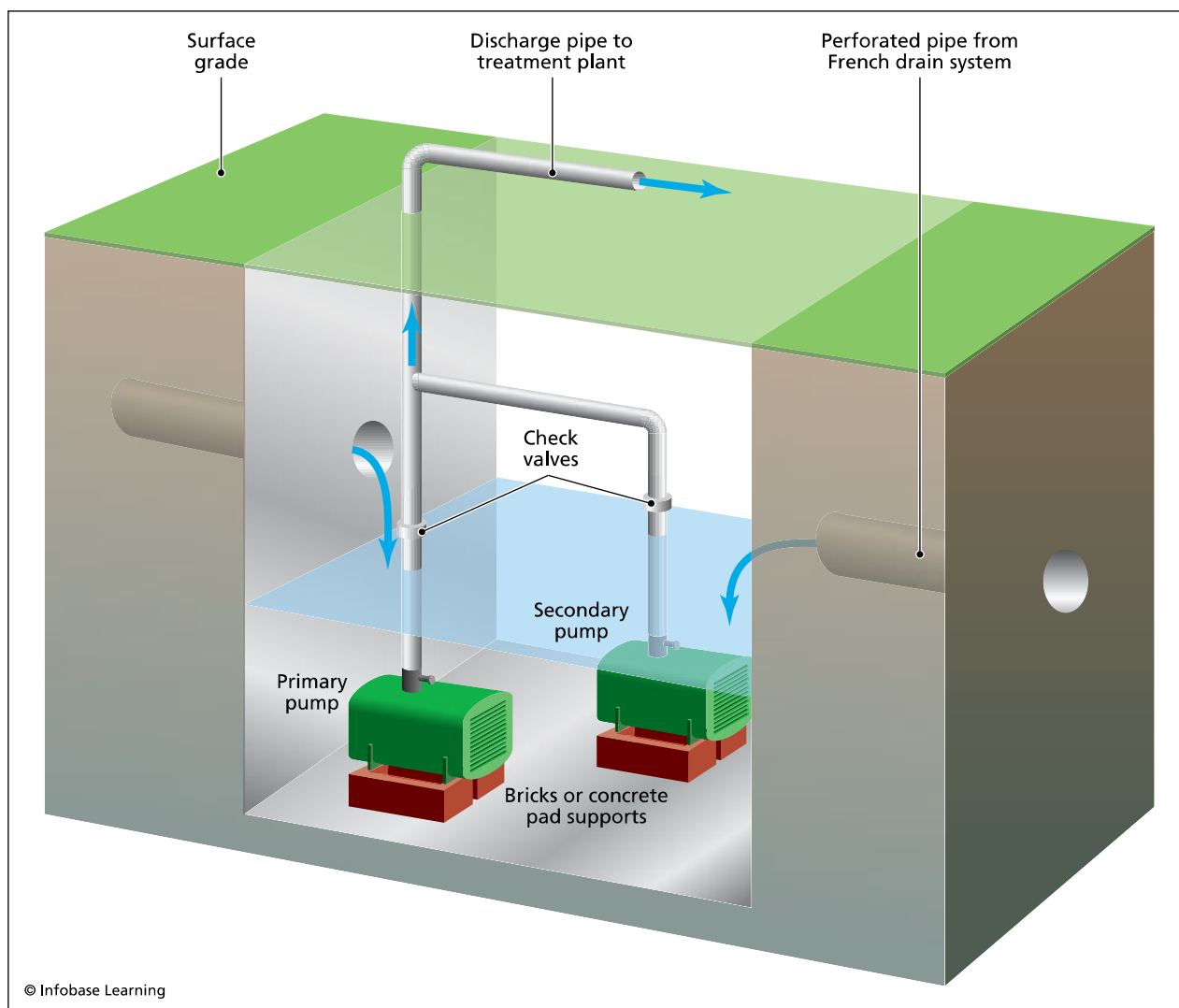
Aerobic cellular respiration uses oxygen as the electron acceptor. Aerobic respiration is effective in treating groundwater contaminated by petroleum hydrocarbons present in gasoline and diesel fuel, especially benzene and naphthalene. Even if no oxygen is available, bacteria have evolved to use other types of electron acceptors to make ATP, and many of these alternate electron acceptors are more commonly available in the subsurface. They include nitrate, sulfate, iron, manganese, and carbon dioxide. The energy available from these alternate electron acceptors is more difficult to extract, with oxygen the easiest and carbon dioxide the hardest.

Anaerobic respiration, more frequently called cellular respiration, uses other electron acceptors such as nitrate, sulfate, or iron. It is not as efficient a producer of ATP as aerobic respiration, but bacteria that use cellular or anaerobic respiration are able to exist in environments that cannot support microbes that rely on aerobic respiration. Bacteria using an aerobic cellular respiration can remediate chlorinated solvents but are generally slower than aerobic respiring microbes in breaking down petroleum hydrocarbons. In situ groundwater bioremediation works on almost all types of petroleum hydrocarbons, but the short-chain, low-molecular-weight, soluble constituents such as kerosene and gasoline are degraded more rapidly and to lower residual concentrations than long-chain, high-molecular-weight, less soluble constituents such as asphalt and paraffin.

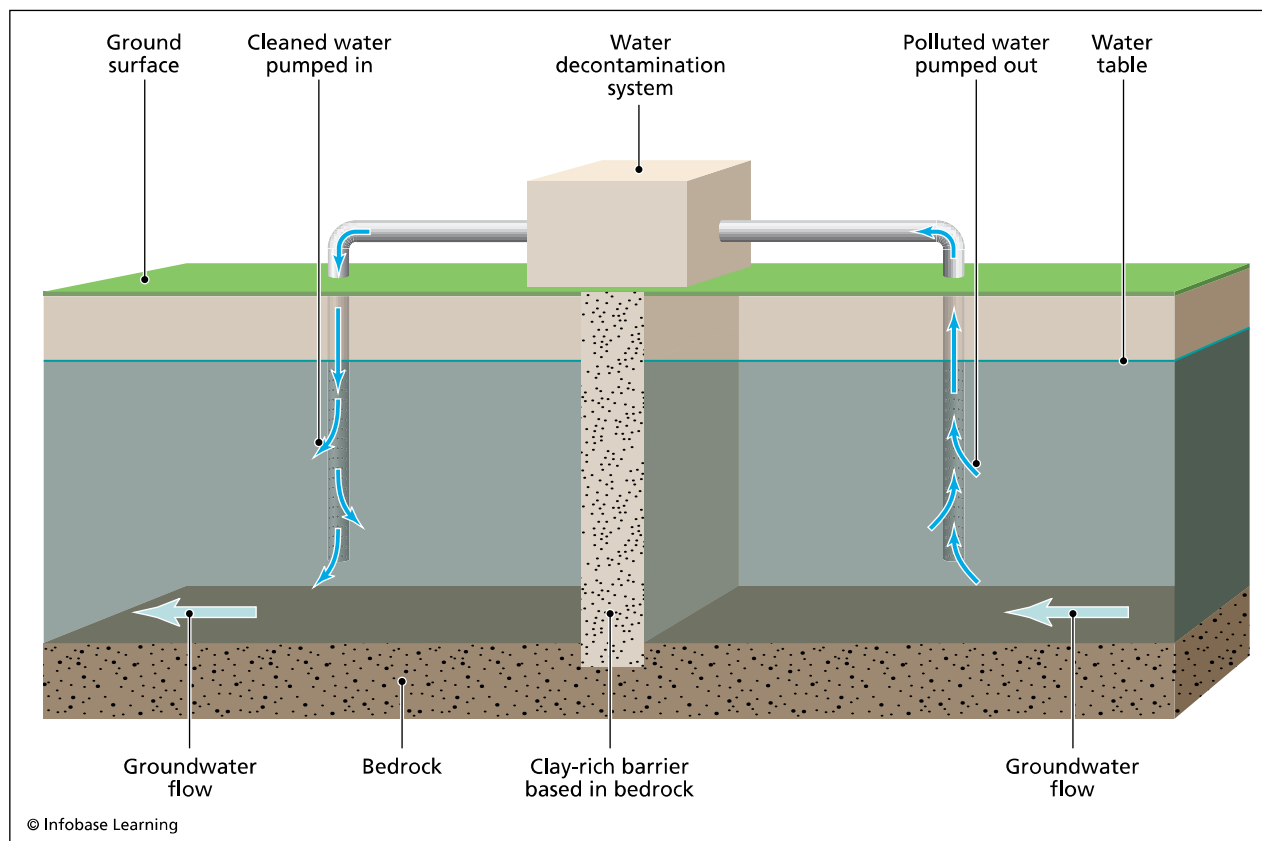
### Field Applications

Before attempting to use an in situ bioremediation technique, it is important to remove as much contaminant from the aquifer as possible. These free product contaminants can act as ongoing sources of dissolved contamination in the groundwater and represent a fire/explosive hazard if they accumulate in basements or sewers. They can also cause significant degradation of indoor air quality if they evaporate and migrate into overlying structures.

Microbial cells are composed of carbon, hydrogen, oxygen, nitrogen, and phosphorus. Within contaminated groundwater plumes, carbon and hydrogen are present in the form of gasoline or some other organic compound that has been released from an underground storage tank (UST), industrial sewer, or treatment lagoon. The whole purpose of enhanced bioremediation is to deliver electron



Cross-sectional diagram of a collection sump-and-pump system for contaminated groundwater



**Cross-sectional illustration of an impermeable (clay) groundwater barrier system with a pump-and-treat water decontamination system to remediate the contaminated groundwater**

acceptors and nutrients such as phosphorus and nitrogen to microorganisms in the subsurface. Once these limiting factors are overcome, the naturally occurring microbial population can attack the contaminant and liberate the carbon and hydrogen for additional growth and reproduction.

One way to introduce the electron acceptor into the aquifer is to extract the groundwater using recovery wells and add electron acceptor and nutrients. The treated groundwater is then reintroduced using injection wells upgradient of or within the contaminant source. Ideally, the water being extracted is treated and then reinjected, and remediation occurs in situ, without the need for an aboveground treatment system.

In situ treatment methods are usually used if the groundwater cannot be collected efficiently by recovery wells, or if the contaminant plume is too small to justify the large capital cost associated with the design and installation of a groundwater recovery system. In these situations, oxygen as an electron acceptor is added to the groundwater by either pumping air into the subsurface through an injection well or adding oxygen through the break-

down of some other inorganic compound such as hydrogen peroxide or magnesium peroxide. These compounds can be introduced through a series of boreholes, temporary well points, or existing monitoring wells.

As with oxygen, nitrate in the form of a salt solution such as sodium nitrate ( $\text{NaNO}_3^-$ ) can be circulated through the contaminant zone as an alternate electron acceptor. Although not used as commonly as oxygen, nitrate has been able to degrade gasoline and fuel oil rapidly through a process called denitrification. Benzene, however, biodegrades more slowly under this type of anaerobic condition. One of sodium nitrate's advantages over oxygen is that it is very soluble in water, delivering 1,000 parts per million (ppm), as opposed to 12 ppm for oxygen. This allows the electron acceptor to be delivered much more quickly and in higher concentrations. If excessive nitrate is added, however, it can migrate beyond the contaminant mass and create a nitrate plume.

Although nitrate is relatively nontoxic, once it is ingested, bacteria in the human body convert it to nitrite ( $\text{NO}_2^-$ ). Until infants are about six months



old, their digestive system secretes very little gastric acid, and the pH level of their digestive tract is higher when compared to an adult's. In this setting, bacteria can proliferate, accelerating the transformation of nitrate to nitrite. Once in the blood, nitrite oxidizes the iron in the hemoglobin of red blood cells to form methemoglobin, which does not have hemoglobin's oxygen-carrying ability.

Iron is a common element that can be an electron acceptor, but its oxidation state is a problem. In groundwater, iron occurs as either reduced soluble ferrous iron ( $\text{Fe}^{2+}$ ) or oxidized insoluble ferric iron ( $\text{Fe}^{3+}$ ). The atmosphere is oxygen-rich, and most of the iron found on and near the surface is oxidized and insoluble ferric iron, in the form of ferric hydroxide ( $\text{Fe}(\text{OH})_3$ ). Ferric hydroxide is a good electron acceptor, and its reduction to ferrous iron by bacteria (called iron reducers) liberates energy that can be used by these bacteria for growth, reproduction, and associated degradation of groundwater contaminants. Ferric hydroxide, however, is not very bioavailable. Once oxidized, the ferric iron quickly precipitates and is bound up in iron-bearing minerals such as hematite or goethite. The red or brown stains, scale, or slime that accumulates in sinks and toilets in homes using iron-rich well water are the result of ferrous iron's being oxidized to ferric iron and then precipitating. These precipitates can plug water pipes or affect the flavor and color of food and water. At high levels, they may also react with tannins in coffee, tea, and some alcoholic beverages, producing a black sludge. Iron can also cause reddish brown staining of laundry, porcelain, dishes, utensils, and even glassware.

It is a slow arduous process requiring just the right supporting geochemical conditions for bacteria to reduce the ferric hydroxide and claim the energy. These geochemical conditions of a fairly narrow range of pH, Eh, and temperature are not widely present in the subsurface, and most of the ferric iron is unused and not bioavailable as an electron acceptor. If sufficient bioavailable ferric iron is present, the reducing bacteria can degrade benzene, vinyl chloride, and other contaminants. This is a biological process, very different from the abiotic use of zero-valent or nanoscale iron to treat contaminated groundwater.

The use of ferric iron as an alternate electron acceptor to stimulate the growth of contaminant-degrading bacteria is possible. There are a number of practical limitations to overcome in introducing and maintaining sufficient quantities of  $\text{Fe}^{3+}$  into the subsurface. To improve its bioavailability, ferric iron must be mixed with organic ligands or chelating agents.

The same processes and limitations that inhibit the use of ferric iron as an alternate electron acceptor also are applicable to manganese. Most manganese in the subsurface occurs as reduced, soluble  $\text{Mn}^{2+}$ . When it has contact with the atmosphere, it quickly oxidizes and precipitates as  $\text{MnO}_2$  in minerals such as pyrolusite. Manganese can cause brownish black stains on clothing and bathroom fixtures. Soaps and detergents do not remove these stains, and the use of chlorine-based bleach intensifies them. In fact, manganese is more of a problem in water at lower concentrations than iron.

Similarly to ferric iron, manganese oxide can be used as an alternative electron acceptor but yields only about half the energy of ferric iron when metabolized by manganese-reducing bacteria. As with ferric iron, manganese oxide reduction can only take place within a narrow range of pH, Eh, and temperature, and its use as an electron acceptor for groundwater remediation is not widespread.

Sulfate reduction, although providing only modest energy yields for the reducing bacteria that change or convert sulfate ( $\text{SO}_4^{2-}$ ) or sulfite ( $\text{SO}_3^{2-}$ ) to sulfide ( $\text{S}^{2-}$ ), takes place as the bacteria utilize organic contaminants in groundwater. The sulfate acts as an alternative electron acceptor that supports the anaerobic respiration of sulfate-reducing bacteria. Unlike iron and manganese, the oxidized form of sulfate is soluble and bioavailable. These characteristics make sulfate a much better candidate as an alternate electron acceptor. Up to about 10 parts per million (ppm) of oxygen can be dissolved in water, but sulfate can have a solubility of almost 120,000 ppm. Sulfate also is considered generally nontoxic and has a secondary maximal contaminant level of 250 mg/L, based on aesthetic effects. An excess of sulfate results in a foul taste and "rotten egg" odor in drinking water. Sulfate is dissolved naturally in drinking water from such common minerals as barite (barium sulfate) or gypsum (calcium sulfate). One of the end products of sulfate reduction is the very poisonous gas hydrogen sulfide, but it is produced in very small quantities and rapidly diffuses to the atmosphere.

In the last stages of organic decay, all the electron acceptors have become depleted, except for carbon dioxide. Methanogenesis, the bacterial formation of methane ( $\text{CH}_4$ ) by the reduction of carbon dioxide, removes the final decay products of hydrogen and carbon. Special types of bacteria, those without a nucleus or membrane-bound organelles, are responsible for methanogenesis. Oxygen is a deadly poison to methanogens, and to survive they must remove it from their environment. Methanogens are present only where there is no oxygen in the digestive tracts

of animals, in deep aquatic sediments, or in subsurface contaminant plumes. Methanogenesis changes organic waste to methane, or natural gas, the same natural gas used to heat houses and power electrical generating stations. In some animals, anaerobic organisms such as methanogens convert cellulose into bioavailable nutrients.

There is no practical way to introduce carbon dioxide as an electron acceptor into the subsurface because it is soluble only in acidic conditions. As soon as the pH increases, the  $\text{CO}_2$  precipitates as the mineral calcite ( $\text{CaCO}_3$ ) or dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ). Also, the reaction rate for methanogenesis is several orders of magnitudes slower than that for other electron acceptors, much too slow to be useful in cleaning up contaminated groundwater. The real value of methanogenesis is as an indicator compound. If methane is detected, all other electron acceptors have been used up and some rate-limiting condition has been reached. An electron acceptor, therefore, needs to be added to the system to continue the in situ cleanup process.

The utilization of electron acceptors occurs in a specific order as bacteria respire nitrate, iron, or sulfate and oxidize carbon-bearing contaminants to support growth and reproduction. These processes can be charted in the field to show which electron acceptor is being utilized at any point within the contaminant plume. A redox map shows how the contaminated groundwater is being broken down as electron acceptors are used up. At the edges of the plume, oxygen is still available and aerobic respiration is taking place. Deeper into the contaminant zone, dissolved nitrate, iron/manganese, and sulfate are consumed. Finally, within the heart of the contamination, carbon dioxide is being consumed and methanogenesis is taking place.

### MONITORED NATURAL ATTENUATION

A number of mechanisms are available in the subsurface to reduce the mass, concentration, toxicity, or mobility of petroleum- and nonpetroleum-based contaminants. These processes operate naturally, without human intervention, and with varying degrees of efficiency, as the groundwater moves through the aquifer. At certain sites, where slow-moving groundwater is not being used by people or the local ecology, it may be sufficiently protective of public health and the environment to do nothing but periodically check on the status of the contamination.

Although viewed with suspicion by communities that have been impacted by contamination, and very carefully evaluated by regulatory agencies, a monitoring-only approach called monitored natural

attenuation, or MNA, can be a valid and justifiable in situ response to some types of groundwater contamination. MNA is usually implemented as a remedy in conjunction with other, more proactive measures such as excavation of contaminant saturated soil or recovery of separate contaminant. It also is sometimes used as the final step in remedial treatment, replacing an in situ or ex situ method that has reached the limits of its effectiveness. A critical part of justifying an MNA remedy is being able to demonstrate that groundwater will clean itself up within a reasonable time frame compared to that for other, more aggressive measures. It generally is not appropriate for contaminants that have a high degree of persistence and toxicity in the environment such as certain types of pesticides or polychlorinated biphenyls (PCBs).

To make a case for MNA as a remedial alternative, three basic pieces of information are needed: the types and vertical and horizontal extents of contaminants, the direction and rate of flow of the contaminated groundwater relative to the community, and the ability of subsurface conditions to support the biological activity necessary to degrade the contamination within a reasonable time frame. The answers to these questions are gathered during a detailed site characterization that collects soil and groundwater samples to delineate or identify where the contamination is present. This characterization program evaluates groundwater flow direction, rate of movement, and the presence of biological activity and electron acceptor breakdown products of carbon dioxide, methane, and so on. Groundwater data are usually collected over a period of years to account for seasonal variations and to show that natural attenuation processes are working. One indication is to determine, through the monitoring data, whether the plume is shrinking, expanding, or staying the same. Another objective of long-term monitoring is to check for the presence of contaminant degradation products, which can be more mobile or more toxic than the original contaminants. Sometimes computer simulations or models can be used to shorten the data-gathering effort and help predict how long natural processes such as nitrification or sulfate reduction will take to reduce contaminant levels to an acceptable concentration. The conditions that affect biodegradation of petroleum hydrocarbons and chlorinated solvents are well known, and the efficiency of natural attenuation can be assessed with a relatively high degree of confidence.

See also AQUIFER; BIOREMEDIATION; DCE; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; MTBE; ORGANIC POLLUTANTS; OZONE; PAH; PCE; TCE; UNDERGROUND STORAGE TANK;

VOLATILE ORGANIC COMPOUND; WATER POLLUTION; WELLS.

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**Ixtoc I oil spill Gulf of Mexico June 3, 1979**  
**Water Pollution** The Gulf of Mexico is a body of marine water, surrounded on three sides by land. To the north and east are the Gulf Coast states of Texas, Louisiana, Mississippi, Alabama, and Florida; to the west and south is coastal Mexico from the border at Matamoros, through Veracruz, Tampico, and Coatzacoalcos to the Yucatán Peninsula at the Bay of Campeche. It is the ninth largest body of water in the world and holds more than 600 trillion gallons (2,271 trillion L) of water. The gulf's roughly 600,000 square miles (1.6 million km<sup>2</sup>) of surface area, 1,000 miles (1,609 km) east to west and 600 miles (966 km) north to south, includes about 3,500 miles (5,633 km) of shoreline and provides habitat for an annual commercial fish and shellfish harvest estimated to be almost 2 billion pounds (0.9 billion kg) and valued at \$700 million.

The more than 200 estuaries that surround the gulf include coastal wetlands, submerged vegetation, upland areas, and marine/offshore areas. The 5 million acres (2.02 million ha) of U.S. coastal wetlands, about half of the national total, are along the gulf. These coastal wetlands serve as an essential habitat for numerous fish and wildlife species, including seabirds, wading birds, and 75 percent of the country's migrating waterfowl. The gulf also serves as a major commercial center. Seven of the busiest ports in the United States are in the gulf, including the port of

Houston, which is ranked first in the United States in foreign waterborne commerce, second in total tonnage, and eighth most active in the world.

The Mississippi River deposits more than 3.3 million gallons (12.5 million L) of water and sediment into the gulf every second, and this discharge accounts for more than 90 percent of the freshwater entering the gulf. Carried along with this freshwater, and intermixed with the entrained sand, silt, and clay, is organic matter including bits of vegetation, animal carcasses, and other once-living debris. Over time, this matter combined with the immense amount of the organic matter from the dying and settling organisms (mostly plankton) in the Gulf of Mexico itself, squeezed and heated by the crushing and unrelenting weight of the overlying sediment, formed large deposits of oil and natural gas. More than 700 billion barrels (29.4 trillion gallons or 112 trillion L) of petroleum and 5,300 trillion cubic feet (150 trillion m<sup>3</sup>) of natural gas is estimated to be present beneath the seafloor in the northern gulf. Extraction of these important hydrocarbon resources provides approximately 20 percent of the U.S. domestic natural gas and 30 percent of its oil. The offshore petroleum industry also employs more than 55,000 workers in the gulf. Mexican hydrocarbon extraction activities produce, on an annual basis, more than 2,500 million barrels (105 billion gallons or 400 billion L) of oil from Gulf of Mexico offshore operations.

#### BACKGROUND

Petroleum exploration and development activities in the U.S. Gulf of Mexico territorial waters are carried out by consortiums of privately owned and operated oil and gas companies. On the Mexican side of the gulf, those activities are the responsibility of PEMEX, or Petróleos Mexicanos, a company owned and operated by the Mexican government. Founded in 1938, partly in response to a strike by Mexican workers against American and European oil companies for better pay and working conditions, PEMEX and its 140,000 employees have made Mexico the fifth largest oil exporting country in the world, and the company contributes almost \$100 million in annual revenue to their economy.

The center of Mexico's gulf oil production is the Bahía de Campeche, or Bay of Campeche. Named for a small, thorny tree that grows in the area, the Bay of Campeche is tucked away into a curve, or bight, of the southern Mexican coastline and is bordered on three sides by the Mexican states of Campeche, Tabasco, and Veracruz. Beneath the quiet waters of the bay, about 50 miles (80 km) off



Oil bubbling into the Gulf of Mexico from the blown-out Ixtoc I well near Del Carmen, Mexico, January 1980 (AP Images)

its coastline is the Cantarell Complex, a collection of five giant reservoirs that make this the second most productive oil field in the world. Discovered in 1976, oil from beneath the Bay of Campeche supplied Mexico with about two-thirds of its crude oil until very recently.

PEMEX moved quickly after the discovery of the Cantarell Complex to begin exploration and development operations. They leased a semisubmersible drilling rig from Sedco, the owner of the rig and a worldwide oil exploration company. This rig was equipped with pontoons and columns, which, when flooded, allow it to sink to a predetermined depth and begin drilling operations. These types of drilling rigs usually are attached to the ocean bottom with mooring chains. Others use a series of computer-controlled dynamic positioning propellers or thrusters mounted on each corner of the platform to keep the rig centered over the borehole. Readily available, usable under a variety of conditions, and inexpensive compared to jack-up and other types of platforms, semisubmersible drilling rigs can operate in water depths ranging from 2,000 to 5,000 feet (610–1,524 m) and are able to be detached quickly and towed to the next location after a well is completed and placed into service.

Initial drilling went very well. The exploratory well, named Ixtoc I, was quickly drilled to a depth of more than two miles (3.2 km) below the ocean floor. During drilling, especially to these great depths, drilling mud, a special mixture of fine silt and clay, is pumped down and through the borehole both to help remove cuttings and rock debris ground up by the drill bit, and to make sure an uncontrolled release, or blowout, of oil or gas does not occur. In addition to the drilling mud, special valves called blowout preventers, or BOPs, are attached to the top of the wellhead. These valves can be closed to contain any oil or gas that suddenly rushes out of the borehole.

### THE BLOWOUT AND SPILL

On June 3, 1979, a sudden loss of drilling mud circulation took place within the two-mile- (3.2-km-) deep borehole of the Ixtoc I exploratory well. Ignoring the advice of several safety specialists working on the platform, workers withdrew a section of drill pipe and started to unscrew it. Oil and mud began gushing out, and, when workers tried to retighten the pipe, the threads jammed. When the crew was unable to secure a safety valve to the



top, special shears were deployed to cut through the pipe, but they were not strong enough. As the overlying mud poured out of the borehole, without the correct amount of drilling fluid to hold back the oil and gas, which was under tremendous pressure, it explosively forced its way out through the top of the wellhead and onto the working level of the semisubmersible drill rig. As the roughnecks and platform operators ran for their lives, the oil and gas spewing from the well ignited, and, within a few hours, the \$22-million burning drilling rig collapsed on itself and sank, settling to the bottom of the Gulf of Mexico and landing directly on the remnants of the now-broken and shattered wellhead, eliminating any possibility of quickly controlling the blowout. Oil was pouring into the Gulf of Mexico at the rate of about 400–1,200 barrels (16,800–50,400 gallons or 63,840–191,520 L) per minute.

One of the first efforts to stop the flow of oil involved the use of a small remote-controlled submersible. This attempt failed because of very low visibility and the presence of platform wreckage near the submerged wellhead, including more than 9,000 feet (2,743 m) of pipe that had been ejected from the borehole. Eventually, volunteer divers were able to approach the wellhead to engage the BOP, which was still mounted there and was acting to restrict partially or slow the flow of oil. They were successful, but the pressure exerted by the now-confined oil and gas continued to build and started to destroy the BOP, so the valves were reopened. Realizing now that there would be no easy solution, PEMEX authorized the drilling of two relief wells adjacent to Ixtoc I. Once they were completed, the oil and gas pumped from these two relief wells reduced the pressure within the Ixtoc I borehole sufficiently to allow a 1,650-foot (503-m) plug of quick-setting cement mixed with bits of canvas, steel, and lead pellets to be pumped into the borehole to stop the flow of oil. That was on March 23, 1980, almost 10 months after the initial blowout and subsequent to the release of more than 3.3 million barrels (139 million gallons or 528 million L) of oil into the Gulf of Mexico.

### THE CLEANUP

As the oil gushed into the waters of the gulf, skimmer ships and booms were positioned to contain and recover as much of it as possible. Prevailing northerly winds, however, began to push the oil toward the Texas coastline. With only two months to prepare for the arrival of an oil slick estimated to be 60 miles (97 km) wide and 70 miles (113 km) long and up to six inches (15.2 cm) thick,

booms were laid across the entrances to most estuaries and oil cleanup crews were placed on standby. Oil first made landfall on the Texas beaches of Port Mansfield Channel and North Padre Island in early August. By September, the entire South Texas coast had been oiled to one extent or another, with mousse and tar balls washing up on beaches and shorelines. Specially developed vacuum sweepers, along with rakes and shovels, were used to clean beaches rather than the more environmentally damaging heavier equipment. Almost 72,000 barrels (3 million gallons or 11.4 million L) of oil washed up on 160 miles (258 km) of U.S. beaches, and more than 10,000 cubic yards (7,646 m<sup>3</sup>) of oiled sand and other material were removed. Bird cleaning stations were set up by the U.S. Fish and Wildlife Service, but only a few dead birds were found, as many avian species bypassed the oil-covered shorelines probably because of contaminated food sources. A total of 1,400 birds were recovered and treated for oiled feathers or feet.

As summer ended, winds shifted, and oil containment efforts near the wellhead gradually became more effective. A bell-shaped cap was placed over the wellhead at the bottom of the seafloor, which helped slow the flow of oil and allowed it to be partially collected and burned at the surface. Aerial applications of oil dispersants were also sprayed regularly on the slick, and oil collecting ships and booms operated around the clock. By mid-September, thanks in part to a storm that helped wash much of the oil off the beaches and push the slick farther out to sea, the worst was over for the U.S. coastline.

The change of season winds and currents started to force the oil toward Mexico. Impacts to Mexican beaches were severe, but the government has been hesitant to release actual data or the results of the limited follow-up studies that were conducted. Newspaper accounts quoting individuals living near the coastlines of Tampico and Matamoros reported that “thousands” of seabirds had been covered with oil and died. The U.S. Fish and Wildlife Service helped airlift thousands of the endangered Kemp Ridley sea turtles from their nesting ground in Tamaulipas to unoiled beaches in other parts of the gulf. These very small hatchlings, which can grow to more than three feet (1 m) long weighing up to 80 pounds (36.3 kg), race to the ocean after breaking out of their shells and are particularly sensitive to oil pollution.

### THE AFTERMATH

PEMEX and the Mexican government denied responsibility for the blowout and refused requests for reimbursement of cleanup expenses or compen-

sation to fishermen and others impacted by the oil that washed up on Texas beaches. Tourism along Gulf Coast resorts declined 60 percent that year. Sedco, the Texas-based owner of the drilling rig operated by PEMEX, paid more than \$2 million in compensation to fishermen and resort owners. The total estimated cost of the blowout was more than \$350 million, including the value of the lost oil.

Since the Ixtoc I disaster, PEMEX continues to be beset by a number of incidents that have had major impacts on its neighbors and have raised questions about the safety of its operating practices. A series of explosions in 1992 at a PEMEX facility in Guadalajara, Jalisco, killed more than 200 people. In 1996, a sequence of massive explosions at the PEMEX petroleum storage facility at San Juan Ixhuatepec, just north of Mexico City, started a fire that killed 500 people. In summer 2007, Leftist rebels reportedly blew up and damaged four sections of a 36-inch-(91.4-cm-) diameter natural gas pipeline operated by PEMEX. These and other incidents, coupled with charges of corruption and dishonesty by many of its service station operators, point to a company struggling to balance its vital role in the Mexican economy with the need to protect the health, safety, and welfare of its operating environment.

*See also* OIL SPILLS; SANTA BARBARA OIL SPILL.

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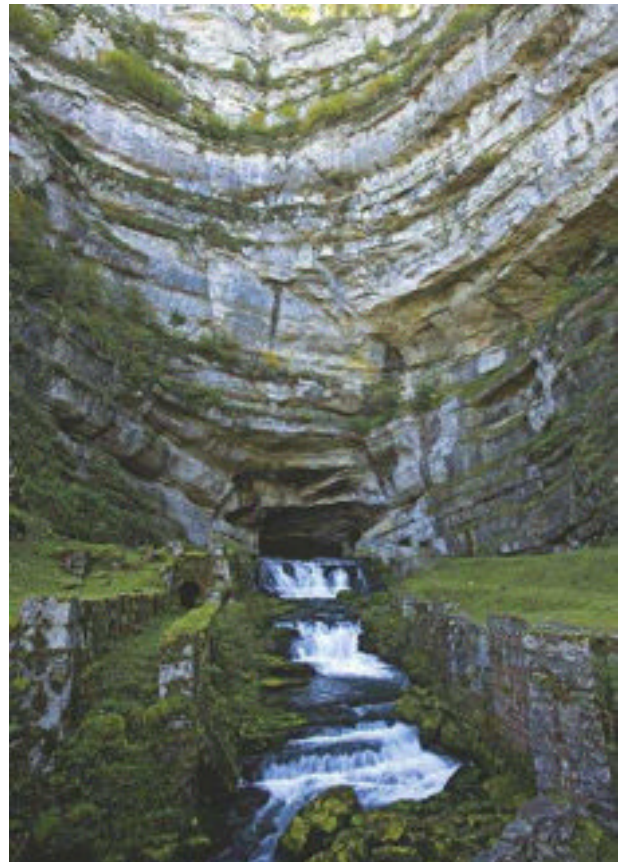
# K

**karst** Karst is a type of landform or topography that forms in areas underlain by limestone and in relatively wet and temperate climates. Meteoric water becomes slightly acidic with carbonic acid through interaction with  $\text{CO}_2$  in the atmosphere and/or rotting vegetation on the surface in wetlands or other wet areas. This acidity can be increased in industrialized areas with the addition of sulfuric acid from sulfur dioxide and nitric acid from nitrogen dioxide, two common air pollutants. On the surface, the acidic waters dissolve the surface of the limestone, reducing the elevation of these areas. The acid waters flow into fractures and joints and dissolve the calcite in limestone below the surface, as well. The fractures expand with continued dissolution, becoming caves and caverns. As the underground cavities expand and interconnect, eventually all surface flow drains underground and flows through them in underground streams. All groundwater is contained within these caves in areas of karst.

Disappearing streams occur where a surface stream drops into an underground stream in a single sinkhole. Even with water in underground streams, the dissolution of limestone continues unabated, and the stream may drop to deeper levels, leaving dry cave and cavern systems in the abandoned upper levels in areas with deeper water tables. There are very few, if any, surface streams or rivers in karst terrains. At times, the roof of the cave can collapse, forming a craterlike sinkhole on the surface above. As is the cave system, the location of the sinkholes is controlled by fractures and fracture systems. Depending upon the severity of the collapse and the development above it, large structures such as buildings, cars, roads, and trains can fall into the cave. In some areas, this is a serious environmental hazard.

## WATER POLLUTION

Karst terrains have severe problems with water quality. Even with no human influence, the water in these areas is extremely hard (or rich in dissolved cal-



The headwaters of the river Loue in the Jura Mountains of eastern France is a spring flowing from a karst cave at the foot of a limestone cliff. (Bob Gibbons/Photo Researchers, Inc.)



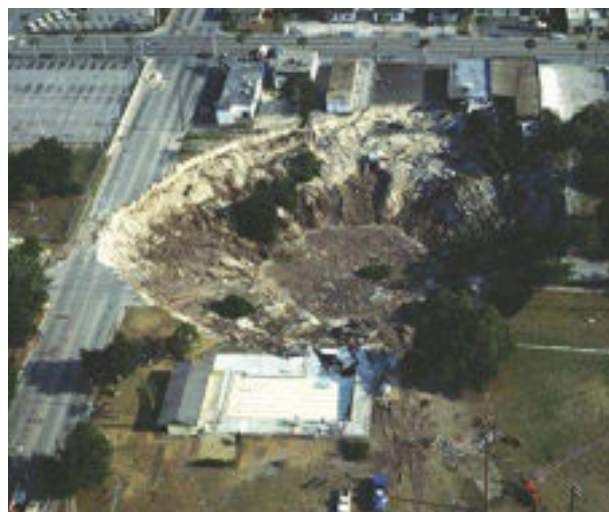


**Sinkhole on John Muir Drive in San Francisco, California, 1998** (AP Images)

cium), a condition that, in most cases, causes no real adverse health effects but will clog pipes and destroy water-bearing appliances. The real problem arises because water flowing through caves is like water flowing through a very large open pipe. There is no mechanical or chemical filtering of the water, as in typical rock and sand aquifers. The water, therefore, contains virtually all the bacteria and pollutants that enter the system all along its course. Runoff from the surface enters the groundwater system directly. This especially creates problems in industrial areas where runoff may flush industrial chemicals into surface waters and directly into the groundwater system. Agricultural areas pose similar threats with fertilizers and pesticides flushed from the fields and into the groundwater.

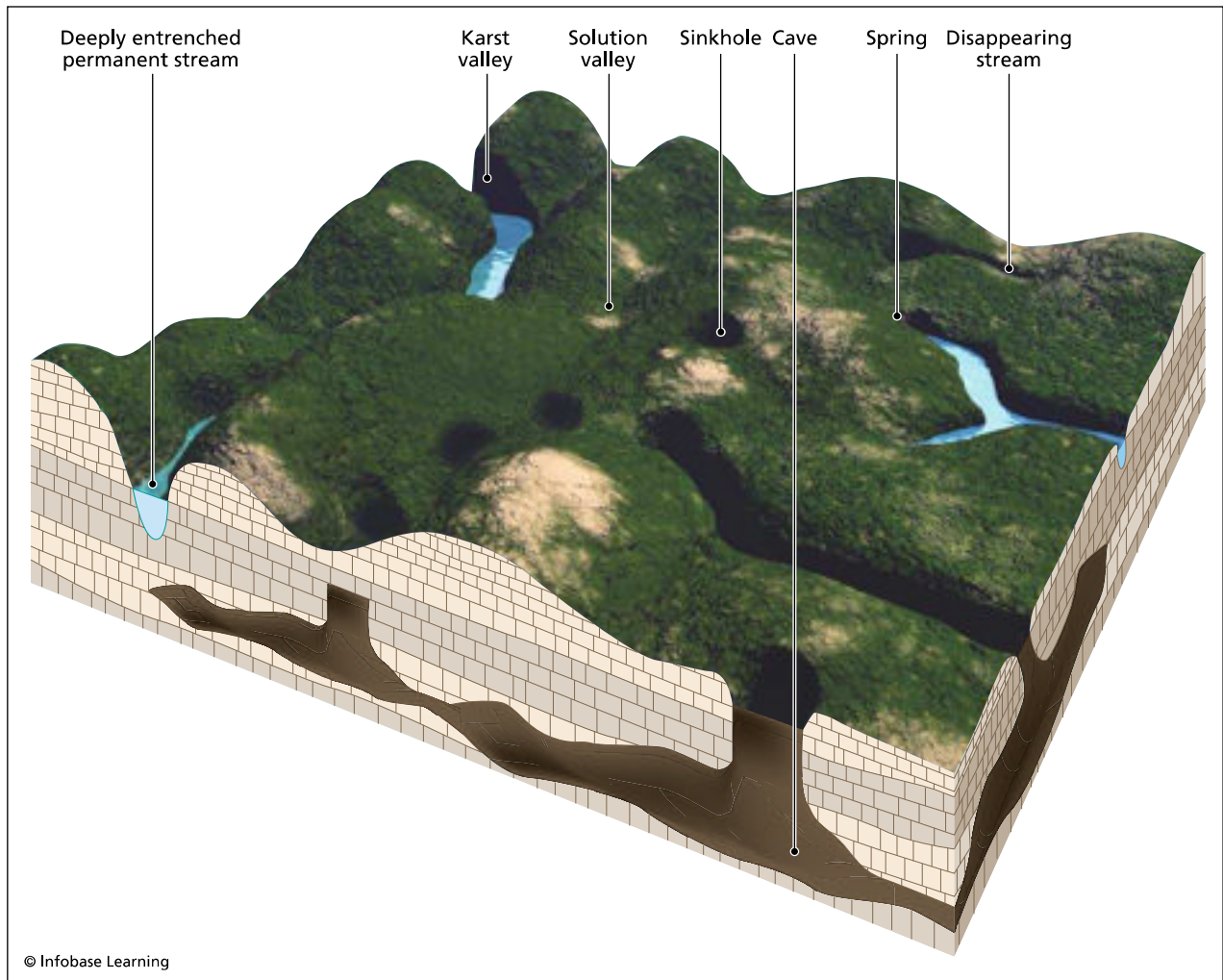
There is a story that in Egypt several chickens fell down a well in a karst area and climbed out of another well about one mile (1.6 km) away, looking no worse for wear. This illustrates the size of particles that can be carried in a karst system. A less comical example occurred in a chemical plant on the Delaware River, New Jersey, where workers arrived in the morning to find a waste lagoon had completely disappeared down a sinkhole during the night, and it was never recovered. Houses, roads,

trains, and many other structures have been known to disappear into sinkholes, either slowly or catastrophically. It is for this reason that karst areas are so environmentally sensitive as well as dangerous to develop. It is important that town planners and engineers avoid siting landfills or any other waste treatment or generating facilities on limestone terrains.



**Sinkhole in Winter Park, Florida, May 1981** (AP Images)





**Block diagram showing the typical surface and subsurface features of a karst terrain in limestone**

Zoning laws should also be carefully designed to protect the water quality.

### **SOME EXAMPLES OF KARST AREAS**

There are several examples of major karst aquifers in the United States. The largest is probably the Floridan Aquifer of Alabama, Florida, Georgia, South Carolina, and a small part of Mississippi. This huge aquifer provides water to tens of millions of people as well as to the major agricultural areas of the country. The burgeoning population in the area and heavy national demand for agricultural products have been a heavy burden for the Floridan Aquifer, which is now suffering from degraded water quality, diminished water supplies, and saltwater incursion along the coastal areas.

The Edwards Aquifer of Texas is also a limestone aquifer with karst development. It has produced some of the most dramatic artesian wells yet

found and has recorded the highest flow rates from wells in the United States. It too, however, suffers from degraded quality and diminished supplies that threaten its unique ecology.

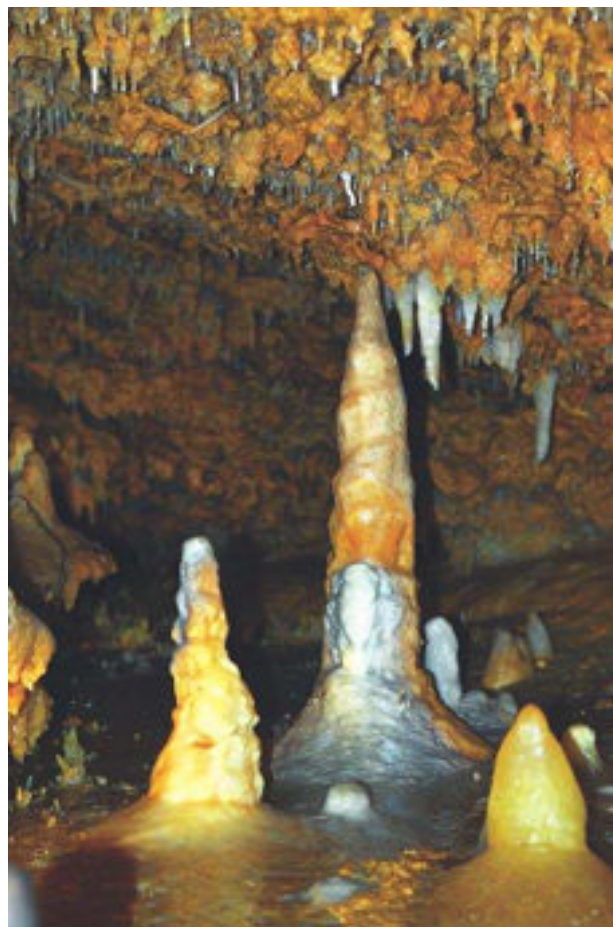
There are numerous other karst areas in the United States that may not have such impressive aquifers but suffer from the same pollution problems. Areas with large caves and cavern systems, by definition, are areas of karst. The Mammoth Caves of Kentucky are part of a huge system that extends into West Virginia and Tennessee, but the limestone that hosts it stretches northward into Ohio and Pennsylvania and southward into Alabama. With other systems including Luray Caverns of Virginia and Howe Caverns in New York, most of the states east of the Mississippi River have karst in at least some area. Only Delaware and a few of the New England states do not have karst. There is also karst in the West, magnificently exemplified by Carlsbad Caverns in New Mexico. Karst is generally less pro-

nounced in the West because of the more expansive arid and semiarid areas.

See also AQUIFER; EDWARDS AQUIFER; FLORIDAN AQUIFER; NO<sub>x</sub>; SULFUR DIOXIDE; WATER POLLUTION.

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Stalagmites and stalactites form in a limestone cavern in the Dordogne region of France (Elena Elisseeva, 2008; used under license from Shutterstock, Inc.)

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#### Kerr-McGee Rare Earths Facility West Chicago, Illinois 1990–present Soil Pollution

The 90-acre (36.4-ha) Reed Keppler Park lies about 30 miles (48 km) west of Chicago, Illinois. Part of the almost 400-acre (162-ha) West Chicago Park District, Reed Keppler Park, or RKP, is one of 13 recreational areas serving this suburban bedroom community of some 30,000. It is used for tennis, swimming, volleyball, soccer, baseball, and softball. Surrounded by quiet residential neighborhoods, RKP's Family Aquatic Center has a 12-foot- (3.7-m-) high waterfall, a flume slide, and a six-lane, 25-yard- (22.9-m-) long lap pool.

#### BACKGROUND

The area encompassing the park was originally a quarry in the early 1900s, providing rock, sand, and gravel for the construction of nearby railroad embankments. When those deposits were depleted in the late 1920s, a large hole in the ground was all that remained. Wanting to fill this pit, the property owners opened the former quarry for use as a commercial waste dump. By 1939, five acres (2 ha) of the site was being filled with household trash, as well as some sandlike material from a local chemical plant, the West Chicago Rare Earths Facility, or REF. Operated by a series of companies between 1934 and 1973, REF extracted and concentrated radioactive elements such as thorium, radium, and uranium for use by private business, as well as by the U.S. government in its atomic energy and weapons programs. These radioactive materials were produced from monazite ore sands.

Monazite is a reddish brown cerium phosphate mineral ( $\text{CePO}_4$ ) that also is an important source or ore of such rare earth metals as lanthanum, neodymium, and praseodymium. These and other rare earth elements extracted from monazite are used in the ceramic and electrical industries, as well as for research purposes. Monazite also can contain trace amounts of uranium, thorium, and radium. It is a hard, erosion-resistant mineral that occurs as isolated crystals in igneous and metamorphic rocks and tends to weather out of these rock masses and become concentrated in placer deposits. These deposits are natural concentrations of heavy minerals that are slowly washed downhill into streams, where the lighter matrix materials are winnowed away or removed. Monazite is mined from placer stream and shorefront deposits in India and Brazil

and along the North Carolina and Florida coastlines. Other types of ore sands containing bastnaesite, a rare earth carbonate mineral, and fluor spar ( $\text{CaF}_2$ ), also were processed at the REF plant.

### **POLLUTION OF THE SITE**

For the almost 40 years that REF operated, sulfuric acid was washed through tons of monazite ore sand to dissolve the thorium and other rare earths trapped within its crystal structure. Although a highly efficient process, acid leaching had two serious drawbacks: It did not remove all of the thorium, uranium, and rare earths present in the monazite, and it left large volumes of sand for disposal.

As do all businesses, REF sought to keep its operating expenses as low as possible, and this included trying to find cost-effective ways of managing its processed sand or tailings, the leftover material from a mill after most of the valuable minerals are extracted. REF started to give its tailings away for use around the West Chicago area, and local builders and developers eagerly accepted the sand for backfill around foundations. Much of this material was spread around the REF site, but a significant amount was sent to the old quarry-turned-landfill and other areas that eventually would become Reed Keppeler Park. By 1967, when the multinational energy company Kerr-McGee pur-

chased REF, the old quarry essentially had been filled and the use of tailings generated from the site ended in the vicinity of the park. Kerr-McGee operated the facility only a few more years and permanently closed REF in 1973.

The tailings contained residual amounts of radioactive elements, primarily thorium, radium, and uranium, at concentrations posing a significant public health risk. As the unstable nuclei of these elements decay, or break down, they produce gamma radiation and give off or radiate charged protons and neutrons. If particles containing these radioactive elements are taken into the body, by either ingestion or inhalation, they can cause severe cellular and tissue damage that can lead to cancer. These radioactive elements have extraordinarily long breakdown half-lives and consequently remain at dangerous levels in the environment for many years. The potential hazards associated with radioactive residuals in the tailings were not widely recognized when the majority of the material was being distributed (1930s through 1960s).

During the early 1980s, the U.S. Nuclear Regulatory Commission (NRC) conducted an aerial radiation survey in the area of West Chicago and detected anomalously high levels of radiation in and around the former REF facility. Subsequent investigations by the EPA identified the source of the radiation and



**Excavated northern part of Kerr-McGee landfill, Illinois** (*Environmental Protection Agency*)



led to the inclusion of the REF on the National Priorities List (NPL) as a Superfund site in 1990. The EPA found that soil at Reed Keppler Park contained 286 picocuries per gram (pCi/g) of total radium with a maximal concentration in excess of 15,000 pCi/g. Most decontamination guidelines in effect at the time required the removal of soil in public areas if total radium concentrations were higher than 5 pCi/g over background levels, which in this area was about 2 pCi/g. Soil with a total radium concentration of greater than 7.2 pCi/g had to be remediated. A curie (Ci), named after Madame Marie Curie, the French scientist and Nobel Prize winner, is equal to a radioactive decay rate of  $3.7 \times 10^{10}$  disintegrations per second. (The prefix *p* stands for “pico,” a modifier meaning  $10^{-12}$ ; one picocurie, or 1 pCi, represents 2.2 radioactive disintegrations per minute.)

### CLEANUP OF THE SITE

The U.S. Environmental Protection Agency (EPA) issued an administrative order that required Kerr-McGee, the generator of the contaminated sand, and the city of West Chicago, the owners of the property, to initiate soil removal activities at the park. Beginning in 1997, radioactive impacted soil from the band shell, tennis courts, and several parking lots began to be excavated. At the old quarry/landfill where the most material was removed, the excavation was extended to below the water table and was not completed until 1999. Each of these areas was backfilled with clean fill, covered with a layer of topsoil, and restored to a usable surface grade. Final restoration activities were finished in 2000. Almost 115,000 cubic yards (87,924 m<sup>3</sup>) of contaminated material was removed and temporarily stored at the REF site. From there, it was packaged and shipped to an NRC-licensed low-level-radioactive-waste disposal facility. By 2002, EPA certified that the RKP site had been remediated and was suitable for unrestricted release.

RKP was not the only area impacted by REF operations. Three related Kerr McGee sites were placed on the National Priorities List as Superfund sites in 1990 or 1991, including the West Chicago Sewage Treatment Plant (STP) site, the Residential Areas Site, and the Kress Creek/West Branch DuPage River Site. Contamination at these locations also originated from REF, and they were remediated separately.

Between 1932 and 1973, REF donated radioactive tailings and process wastes from its operations for use as backfill and in stream bank stabilization projects at the West Chicago municipal STP. Some of this material was also mixed with landfill

wastes, and, as a result, soil was contaminated at the site. Tailings were also used as fill along an approximately 320-foot (97.5-m) section of riverbank. Over time, as a result of flooding and erosion, thorium residuals were distributed in other areas of the stream banks, floodplain, and bottom sediment.

At the STP site, radiation surveys identified an estimated 57,000 cubic yards (43,580 m<sup>3</sup>) of contaminated soil that had to be removed and disposed of properly. This was done between 1986 and 1987, but the cleanup criterion used later was found to be too high, and a second removal action focused on additional material under or beside outfalls along the bank of the river. This second removal action resulted in the excavation of an additional 6,400 cubic yards (4,885 m<sup>3</sup>) of material. River areas impacted by REF tailings were remediated through the removal of approximately 2,200 cubic yards (1,682 m<sup>3</sup>) of targeted soils and sediments (with activities above 7.2 pCi/g) by excavation. Collected wastes were packaged and shipped to an appropriately licensed low-level radioactive waste disposal facility.

Prior to excavation, targeted areas were dewatered to allow soil and sediments to dry out before they were removed. Part of the remediation included the removal, staging, and redeposition of more than 1,100 cubic yards (841 m<sup>3</sup>) of clean soil. After excavation activities were completed, a series of mitigation and restoration activities were implemented to restore aquatic and terrestrial areas that had been disturbed, including revegetation and stream bank restabilization. Later monitoring and maintenance of restored areas demonstrated that excavated areas had been restored as productive ecological habitat.

Residential properties in West Chicago also were impacted by REF. Radioactive tailings used as fill materials, sometimes mixed with topsoil, were deposited around buildings and in gardens and yards. In addition, tailings were used as filler in cement in some areas that later was used in structural foundations. In 1994, acting in response to a recommendation made by the Agency for Toxic Substances and Disease Registry (ATSDR), the EPA prioritized and began to excavate and dispose of those materials that posed the highest public health risk. These were homes with tailings adjacent to their foundations or under them in crawlspaces. Eventually more than 1,300 residential properties were evaluated for the presence of airborne gamma radiation and radon concentrations. Both surface and subsurface soils outside these homes were sampled and analyzed for the presence of thorium, radium, and other radioactive constituents. By 2002, the study area expanded to almost 2,200 properties. The EPA documented contamination in 31 percent of the homes tested.



Kerr-McGee arranged for the removal of the contaminated material from all of the impacted residences. More than 113,000 cubic yards (86,395 m<sup>3</sup>) of soil and related debris was removed and shipped to an NRC-licensed disposal facility, including contaminated soil from two schools. A former Kerr-McGee laboratory was found to contain too much mercury and thorium and subsequently was demolished after several attempts at decontamination had left the building structurally unsound. Today, the residential and other off-site properties impacted by placement of REF tailings do not present a public health hazard because the radioactive materials have been removed and there is no ongoing exposure to local residents or building inhabitants.

The Kerr-McGee Kress Creek/West Branch of DuPage River site (DuPage) is another West Chicago Superfund site contaminated with thorium and other radioactive wastes from the REF facility. The site became polluted over time as surface water runoff from REF entered a storm drain and discharged radioactive particulates washed from the site into Kress Creek. From there, stream flow moved this contamination downstream to the West Branch DuPage River. Approximately 1.5 miles (2.4 km) of Kress Creek, from the REF storm sewer drain to the creek's confluence with the West Branch DuPage River, and approximately 5.2 miles (8.4 km) of DuPage River, downstream to the McDowell Dam were impacted.

To remediate these watercourses, Kerr-McGee spent \$70 million to excavate impacted sediments of nine segments of the stream, starting with the most contaminated upstream areas closest to REF and moving to least contaminated downstream sections. Cleanup work began in 2005 and was completed in 2008.

On June 23, 2006, the Anadarko Petroleum Corporation acquired Kerr-McGee in an all-cash transaction totaling \$3.4 billion. Kerr-McGee immediately ceased to exist as an independent entity. Its Superfund cleanup obligations at West Chicago and in other areas of the country will continue to be paid for by a special fund established by the company prior to its acquisition and dissolution.

See also RADIATION; RADIOACTIVE WASTE; RADIUM; RADON.

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#### Kingston coal ash release Roane County, Tennessee December 22, 2008 Water and Soil Pollution

Since the late 1700s, navigation on the 650-mile (1,050-km)-long Tennessee River had been problematic. The river is divided into an upper region north of Muscle Shoals, Alabama, and an eastern, lower region in Tennessee, separated by a 35-mile (56-km) series of rapids along which the river drops 130 feet (39.6 m) in elevation. As the largest tributary of the Ohio River and one of the major watersheds in the United States, its often erratic and unpredictable character seriously hampered commerce within the seven states through which the Tennessee River flows. In an effort to stabilize the river, the War Department (later Department of Defense), in cooperation with the U.S. Army Corps of Engineers, constructed the Wilson Dam in 1925 at Muscle Shoals, in part to harness the hydroelectric potential of the drop in elevation. This electricity was needed to make nitrate for World War I munitions and, after the war, agricultural fertilizer. The political debate over the ownership of the dam and the future development of the river, however, emphasized the need for a regional approach to its management.

#### DEVELOPMENT OF THE TENNESSEE VALLEY AUTHORITY

To provide the managerial structure for efficient development of the resources of the Tennessee River valley, Congress passed the Tennessee Valley Act in May 1933 as one of President Franklin D. Roosevelt's (1882–1945) innovative and controversial

New Deal programs. This act authorized the formation of a government-sponsored corporation, the Tennessee Valley Authority, or TVA, whose statutory mission was to plan for and carry out “. . . the proper use, conservation, and development of the natural resources of the Tennessee River drainage basin and its adjoining territory for the general social and economic welfare of the nation.” For the politicians, engineers, and managers who helped form the TVA, the organization would allow construction of transmission lines and the provision of electricity at reasonable rates to rural areas not being served by private utilities.

In the early 1930s, only about 10 percent of households outside of cities had electricity. Farmers could not take advantage of modern technologies (such as automatic milking equipment or irrigation pumps), and their ability to store agricultural products under sanitary conditions was limited, which affected the competitiveness of U.S. agriculture. In addition, nonfarm industries were hesitant to build manufacturing centers in areas without reliable and cost-competitive electric service. Privately owned power companies were convinced that farmers in rural areas could not afford and would not use electricity, even if they could profitably build the distribution system to supply it. Although some rural communities formed nonprofit cooperatives to supply electricity, these efforts were largely ineffective because they lacked the technical and financial skills to be successful. As the TVA began to generate significant amounts of abundant, cheap power, first through hydroelectric plants and later using coal, another critical piece of New Deal legislation was passed: the Rural Electrification Act (49 Stat. 1363) of 1936. This act allowed the federal government to make long-term, low-interest rate loans to nonprofit, rural cooperatives that sought to bring electricity to their communities. The act, and its administering body, the Rural Electrification Administration, or REA, provided a stable source of funding to enable development and distribution of electricity to rural areas.

Today, the TVA owns and operates 29 hydroelectric dams, 11 coal-fired steam plants, 16 solar power sites, six combustion turbine plants, and three nuclear power plants. It is the United States's largest public power provider, serving approximately 8.5 million people and 650,000 businesses. The TVA provides electricity at costs that are about 25 percent lower than the national average while maintaining 158 power distributors, 17,000 miles (27,359 km) of power transmission lines, 117,000 transmitter struc-

tures, and 1,025 interchange and connection points across a seven-state region.

### THE KINGSTON PLANT

One of the largest electrical generating stations in the TVA's coal-fired fleet is the Kingston Fossil Plant on the Watts Bar Reservoir of the Tennessee River near Kingston, Tennessee, about 35 miles (56 km) west of Knoxville. From 1955, when TVA commissioned the plant, through the mid-1960s, Kingston was the largest coal-burning power plant in the world. Kingston's nine coal-fired units generate electricity by burning coal to turn water into steam. Under high pressure, the steam is directed to a turbine that spins a generator that produces electricity. Kingston produces about 10 billion kilowatt-hours of electricity a year, enough to power 670,000 homes.

The burning of this much coal results in about 360,000 cubic yards (275,240 cubic m) of by-product or ash. The makeup of coal by-products (ash) is highly dependent on the source of the coal but generally consists of noncombustible minerals such as quartz and other siliceous (silica-bearing) compounds. Toxic heavy metals such as uranium, lead, mercury, and arsenic also can be present in the ash.

Bottom ash that makes up about 20 percent of the residue consists of a heavy, rough mixture of minerals and waste materials that collects at the bottom of the boiler. Fly ash constitutes about 75 percent of the residue and is made up of light, finer particulate present in hot flue gases and trapped by filters and scrubbers. Boiler slag makes up about 5 percent of the residue and is formed when ash melts under intense heat of the combustion process. It typically collects in exhaust stack filters.

Residues (up to 10 percent of the volume of consumed coal) at Kingston are flushed out of the boilers and exhaust stacks and temporarily stored in settling basins. Periodically, these basins are emptied, and many utilities have successful recycling programs for the residues. As an example, there is a thriving market for fly ash as an additive in concrete. Those materials, which have less value (e.g., bottom ash and boiler slag) are removed from the settling basins and placed in a surface impoundment or landfill for permanent disposal. The landfills are usually located near the power plants. Utility company engineers design and construct these disposal units to isolate the coal residues from the environment and minimize the risk of potential negative affects to local surface and groundwater from leachate.

The nine generating units at the TVA Kingston power facility consume vast amounts of coal

and produce corresponding amounts of residues. At normal operating conditions, electric power generation consumes approximately 14,000 tons (12,700 metric tons) of coal per day and produces about 1,000 tons (907 metric tons) of fly ash. Plant operators sluice this fly ash, along with boiler slag and bottom ash, to a settling basin where the residues sink to the bottom. As the basin fills, it is dredged and the ash is moved to one of three dredge cells or compartments within a long-term surface impoundment. Like many coal-burning power plants, the design and construction of ash management impoundments proceeded on almost an ad hoc basis, with the impoundments constructed and expanded as needs for storage capacity increased. At Kingston, residues initially were placed in a 59-acre (24-ha) pond north of the generating units. Surrounding the impoundment were earthen berms or dikes (walls) constructed from soil scraped from the bottom of the pond. As the impoundment grew, horizontally and vertically, TVA engineers used ash, local and imported soil, and other materials to widen and extend the enclosing dikes. TVA did not have a systematic approach to dike design, inspection, or maintenance, and quality assurance controls and procedures typically used during construction of these kinds of high-risk structures apparently were not priority items.

### **COLLAPSE OF WASTE IMPOUNDMENT**

Clarified water from the waste residue flowed from the impoundment into the nearby Emory River through a spillway that is permitted and monitored by the Tennessee Department of Environmental Conservation (TDEC). As the height of the dikes grew, sidewall waste and water pressure increased and small dike failures or blowouts began to occur. In 2003 and 2006, minor slope failures or sloughs took place that led to waste ash escaping from the impoundment. By 2008, the dike walls towered over 80 feet (24.4 m) higher than the Emory River and some 40 feet (12.2 m) above a local, well travelled roadway. In mid-December 2008, the dredge cells covered 84 acres (34 ha) and contained almost 10 million cubic yards (7.6 million m<sup>3</sup>) of coal combustion residues.

Eventually, the hodge-podge system of inadequately designed and constructed dikes could no longer withstand the increasing waste and water pressure from the ever-increasing volume of fly ash and bottom ash that Kingston plant operators were pumping into the impoundments. At about 1:00 A.M. on December 22, 2008, after a period of wet-

ter than normal weather, the dike system along the northern side of the dredge cells failed and catastrophically released approximately 5.4 million cubic yards (4.1 million m<sup>3</sup>) of coal combustion residues. These residues gushed from 50 acres (24.3 ha) of the dredge cells into local streams and onto the land surface. A wave of sludge roiled out of the impoundments, destroying a local roadway (one regularly used by school buses), knocking one home off its foundations, rendering two others uninhabitable, and depositing a several-foot-thick layer of black contaminated ash sludge over approximately 300 acres (121 ha). Fortunately, there were no fatalities or major injuries that occurred as a result of the release, but electrical, gas, and water service was interrupted, a 2,000-foot (610-m) stretch of rail line that serviced the Kingston power plant was destroyed; and more than 40 homes were temporarily evacuated. It was the largest coal ash release in U.S. history.

The TVA responded quickly and effectively to address the disaster. Emergency response procedures activated by the TVA provided alternate housing for affected residents, and they continue to work with homeowners to restore and rehabilitate their land and properties. The TVA also was able to reestablish utility service to the area over the next few weeks and rebuild the damaged rail line. They installed and still operate air, surface water, and groundwater monitoring systems to evaluate and monitor potential public health and ecological effects related to the release, and they share all information with the U.S. Environmental Protection Agency (EPA), the TDEC, and the local community. The TVA has retained a number of outside experts to evaluate short- and long-term impacts to local ecology, including fish and benthic organisms in the Emory River. All of the actions that the TVA has taken in response to this release have been done under the oversight and supervision of the EPA and the TDEC. Cleanup, compensation, and repair costs are expected to be in the tens of millions of dollars and are not likely to be completed until 2012. Even with this response, lawsuits were filed against the TVA by the residents of the area totaling \$165 million, and the EPA declared the release to be an illegal contamination of the river.

The TVA used the Kingston release as the impetus to review and assess coal combustion residue management practices at all of its generating facilities. As a result, significant management and organizational changes have taken place, causing a major refocusing and commitment to safely store and dispose of these materials.

### OTHER EXAMPLES OF RELEASES

Catastrophic releases of waste from residue impoundments have also occurred at other coal-burning power plants in the United States. In 2005, a pipe failure at a generating station in Pennsylvania resulted in the discharge of 100 million gallons (379 million L) of contaminated water and fly ash into the Delaware River. Coal ash residues placed in a former sand and gravel quarry in 2007 and 2008 may have contaminated drinking water wells with heavy metals for almost 100 homes in a Maryland community. In 2009, investigations were under-way in Florida to evaluate whether an ash pile had contaminated a shallow aquifer. Also in 2009, a coal ash release of 4,500 gallons (17,034 L) from a pipeline contaminated a lake in West Virginia. In response to the Kingston and these other coal ash releases, in June 2009 the EPA designated 44 coal combustion residue surface impoundments across the United States as “high hazard,” where a slope or retention wall failure could cause loss of human life, significant economic impacts, and/or major environmental damage. In December 2009, the EPA began a major nationwide review of how coal residues are managed, stored, and disposed.

See also LANDFILL; LEACHATE; PARTICULATE; PARTICULATE AIR CONTROL DEVICES; POINT SOURCE AND NON-POINT SOURCE POLLUTION; STREAMS.

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**Kirkwood-Cohansey Aquifer** The Atlantic Coastal Plain Province sediments underlie the eastern edge of northern Virginia, Maryland, and New Jersey; the entire state of Delaware; and parts of Long Island, New York. The upper unconfined aquifer in southern New Jersey is known as the Kirkwood-Cohansey

Aquifer, the largest aquifer east of the Mississippi River and one of the largest and most productive in the United States. This aquifer contains upward of 17 trillion gallons (65 trillion L) of water underlying 3,000 square miles (7,680 km<sup>2</sup>) of southern and central New Jersey, provides drinking water for 700,000 residents, and even helps to service significant agricultural land in the area. This huge aquifer was considered impervious to water withdrawal and pollution problems that plague other aquifers. Over the years, however, progressively infringing contamination has degraded the water quality over an ever-increasing area, thereby putting both of these claims into peril. The pollution of the Kirkwood-Cohansey Aquifer has now become a major concern of the legislative bodies in all of the areas it serves.

### STRATIGRAPHY OF THE AQUIFER

The Atlantic Coastal Plain sediments began to be deposited in the Cretaceous period about 70 million years ago as the Atlantic Ocean began to open in earnest. The rapid growth of this basin submerged the shorelines and initiated a period of semicontinuous sedimentation that continues today. The early deposition was erratic, with many different environments producing many different kinds of sediments. The low energy of the system in several areas allowed the deposition of a number of thick clay units that were mined in the late 19th and early 20th centuries for ceramics. The first dinosaur bones ever found in North America were in one of these units in New Jersey. Once the ocean basin became wide enough, clean beach sand began to be deposited similarly to the current situation. The only breaks in the sand deposition were from retreats of the ocean during ice ages. At those times, the sea level dropped up to 200 feet (60 m), exposing the deposited sediments to erosion and reworking in terrestrial systems. These periods of sea level retreat are marked by confining clays and phosphate-rich layers called green sands. The clean sand that was deposited on the beaches during times of normal sea level makes the best aquifers because it can store and transmit groundwater better than the other units. The Kirkwood-Cohansey Formations that constitute the Kirkwood-Cohansey Aquifer are composed of beach sand sediment. This unit is more than 6,500 feet (2,000 m) thick at its eastern edge but thins out to 0 feet westward.

### WATER PRODUCTION FROM THE AQUIFER

The water from the unconfined Kirkwood-Cohansey Aquifer has been historically considered the cleanest



available. The surface through which surface water enters the groundwater system, known as the *recharge zone*, includes the protected Pine Barrens of southern New Jersey, which contains extensive wetlands that filter the water both chemically and biologically. The water has been historically regarded as so clean and plentiful that in the late 19th century, the city of Philadelphia, Pennsylvania, attempted to commandeer it for its own use. The state of New Jersey stepped in at the last minute to prevent the plan from being executed. The aquifer has outstanding porosity and permeability in the clean beach sand. High-capacity production wells used for public drinking water supplies commonly yield 500–1,000 gallons (1,900–3,800 L) per minute, and many exceed 1,000 gallons (3,800 L) per minute with an apparently unlimited supply. It is estimated that about 200,000 private wells draw water from the Kirkwood-Cohansey Aquifer.

### WATER QUALITY AND POLLUTION

The once-enviable water quality of the Kirkwood-Cohansey Aquifer has degraded appreciably in recent years, and there have even been several health scares as a result. In general, water quality is considered satisfactory except for several local excessive iron concentrations. In these areas, the water must be treated in a water softener; otherwise, clothes and appliances, among other items, will be stained red. In some coastal areas, the unconfined Kirkwood-Cohansey Aquifer system experiences brackish or saltwater incursion into the freshwater supply. This incursion has been steadily increasing with the combination of increased water usage and sea level rise. The water is also very acidic with no material available to buffer it. It can be very corrosive to pipes, water-bearing appliances, and pumps, among others.

There is also significant anthropogenic pollution that is progressively degrading the Kirkwood-Cohansey Aquifer to deeper levels. The naturally occurring acidic groundwater in much of the aquifer has a low enough pH to extract lead from plumbing, producing unacceptably high levels in the drinking water in a number of homes. The acidity is the result of excess  $\text{SO}_4$  ion concentrations in the water. There are also numerous pollutants from agricultural activities that yield elevated concentrations of  $\text{NH}_4$ , B, Cl, and  $\text{NO}_3$  ions in groundwater. These, in addition to the acidity, can dissolve naturally occurring radium and mercury in some of the geologic units. High radium concentrations in the Kirkwood-Cohansey Aquifer system were found to exceed the maximal contaminant level in 33 percent

of 170 wells tested and estimated to affect as many as 200,000 private wells in six New Jersey counties. These high radium contents are associated with low pH and high nitrate concentrations. High radium levels in wells from agricultural areas are associated with recharge of agricultural return flows, which induces nitrification and reduces pH. Such a combination enhances the extraction of radium from clay minerals and consequently increases the radium levels in the associated groundwater. Mercury appears to be elevated in groundwater by the same process, and about 600 domestic wells were found to exceed the maximal contaminant level (MCL) set by the U.S. Environmental Protection Agency.

Not all of the inorganic pollution problems are related to extraction from natural sources. In Vineland, New Jersey, there is an arsenic plume from a pesticide factory that is the longest traveled in the world. The arsenic enters the groundwater system from the industrial site and is transported tens of miles to a stream, eventually reaching the Atlantic Ocean. The high permeability of the aquifer, in this case, is detrimental to the environment.

Organic pollutants were also found to be elevated in many of the wells that penetrate the Kirkwood-Cohansey Aquifer. In a recent study, chloroform, methyl tert-butyl ether (MTBE), trichloroethane (TCA, TCE), tetrachloroethylene (PCE), and carbon disulfide were detected frequently at low-level concentrations in a network of 78 shallow wells in the surficial Kirkwood-Cohansey Aquifer system. Considering the number of Superfund sites within the aquifer, this is not surprising. The Naval Weapons Station Earle site in Monmouth County, New Jersey, is a Superfund site that is situated in the recharge area of the Kirkwood-Cohansey Aquifer system. This project is attempting to address the paints and paint thinners, solvents, varnishes, shellac, acids, alcohols, caustics, pesticide, herbicide, rinse water, live and spent ordinance, and fuel that were regularly dumped there for a number of decades. The Iceland Coin Laundry Area Ground Water Plume is a regionally extensive TCE Superfund site in Vineland, New Jersey. Operations at the Fort Dix military facility included dumping volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals into the ground, which also contaminated the water in the Kirkwood-Cohansey Aquifer. The area is also now a Superfund site. The Price's Pit Superfund site, which includes virtually every major organic and inorganic pollutant possible, also affects the aquifer, though not directly.

*See also* AQUIFER; CHLOROFORM; COASTAL PLAIN DEPOSITS; MERCURY; MTBE; PCE; PESTICIDES; PRICE'S PIT; RADIUM; SUPERFUND SITES; TCA; TCE.

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# L

**landfill** The largest human structure by volume ever built is not the pyramids or a stadium; it is the Fresh Kills Sanitary Landfill. This huge heap of garbage on Staten Island, New York, is 146 feet (45 m) high and 146 feet (45 m) deep and covers an area of 296.5 acres (120 ha). Landfills have existed in

and around cities for thousands of years. The first documented municipal waste dump is believed to have been established around 500 B.C.E. in Athens, Greece, but waste dumps were used on a local basis far before then. Simple landfills, known as dumps, historically were called middens and were either



Active landfill in western Washington State (Doug Wilson/Alamy)



public or private. In dumps, refuse of all sorts has been simply dumped on the surface and allowed to degrade with time. Town or municipal dumps were specific sites where refuse was disposed of in areas where there was a significant population. In rural areas, dumps of household refuse were located in a convenient place on the property, commonly behind an outbuilding or rock wall. Depending upon the composition of the refuse, they ranged from little more than an eyesore and a possible physical hazard to a serious threat to public health and a breeding ground for vermin. In 1976, the U.S. Congress passed the Resource Conservation and Recovery Act (RCRA), which required that all dumps be converted to sanitary landfills. In modern terms, landfills are either municipal or hazardous waste types.

Although RCRA was the most significant step in the history of landfills, there was other legislation as well. In the 1940s and early 1950s, the vast amounts of waste being generated at an industrial and at a public level began to become a problem. In response, the issue was investigated by the federal government. In 1953, a committee of the U.S. Public Health Service (USPHS) and the American Public Works Association (APWA) published recommended guidelines for refuse collection and disposal practices for a small community. The guidelines were just recommendations for states and were not enforceable regulations. In 1961, the USPHS developed a set of recommendations of standards for sanitary landfill operations to be enforced on a state-by-state basis. In 1965, with the passage of the Solid Waste Disposal Act, the USPHS accelerated its efforts to incorporate sanitary landfill practices into waste repositories within the United States. When the U.S. Environmental Protection Agency (EPA) was created in 1970, the solid waste program was moved from the USPHS to its jurisdiction. It took several years of lobbying to gain support for the sweeping changes of RCRA in 1976 but none as difficult as changing from an advisory to a regulatory status. Even then, full regulatory authority over landfills and direction of the preparation of landfill criteria were not granted until Congress passed the 1984 RCRA Hazardous and Solid Waste Amendments. The EPA responded with a very complete set of criteria known as Subtitle D for adoption by the states.

### PLACEMENT OF LANDFILLS

Finding a suitable location for the placement of a landfill is usually an arduous process. Residents of an area rarely want a landfill near their property because they fear the degradation of quality of life from the odor and stigma and reduction in their



Edgeboro landfill in East Brunswick, New Jersey, ca. 2001  
(AP Images)

home and property value. This issue has been called the “not in my back yard” syndrome. A debate typically ensues that pits irate residents against legislators, and it can escalate into a real battle. This sort of political battle can rage on for years and can impact the more important issue of the physical constraints on the location, which involve both geology and topography. Landfills must be set in lots that are large enough to contain the entire landfill and all the monitoring and administrative facilities, be well removed from populated areas, and yet be close enough that transportation costs do not become prohibitive. They cannot be on hill-tops or steep slopes because these areas can be physically unstable. They cannot be in wetlands or anywhere in which they might impact the water table. The waste and leachate generated by landfills can pollute the water supply and do significant damage to the ecology. This causes further debate because surface depressions are really the best features for containment and yet as such are closer to the water table. It is best to have a ready source of soil to cover the waste, so fresh bedrock surfaces are also undesirable. Finally, certain rock types are not ideal even though they are commonly used

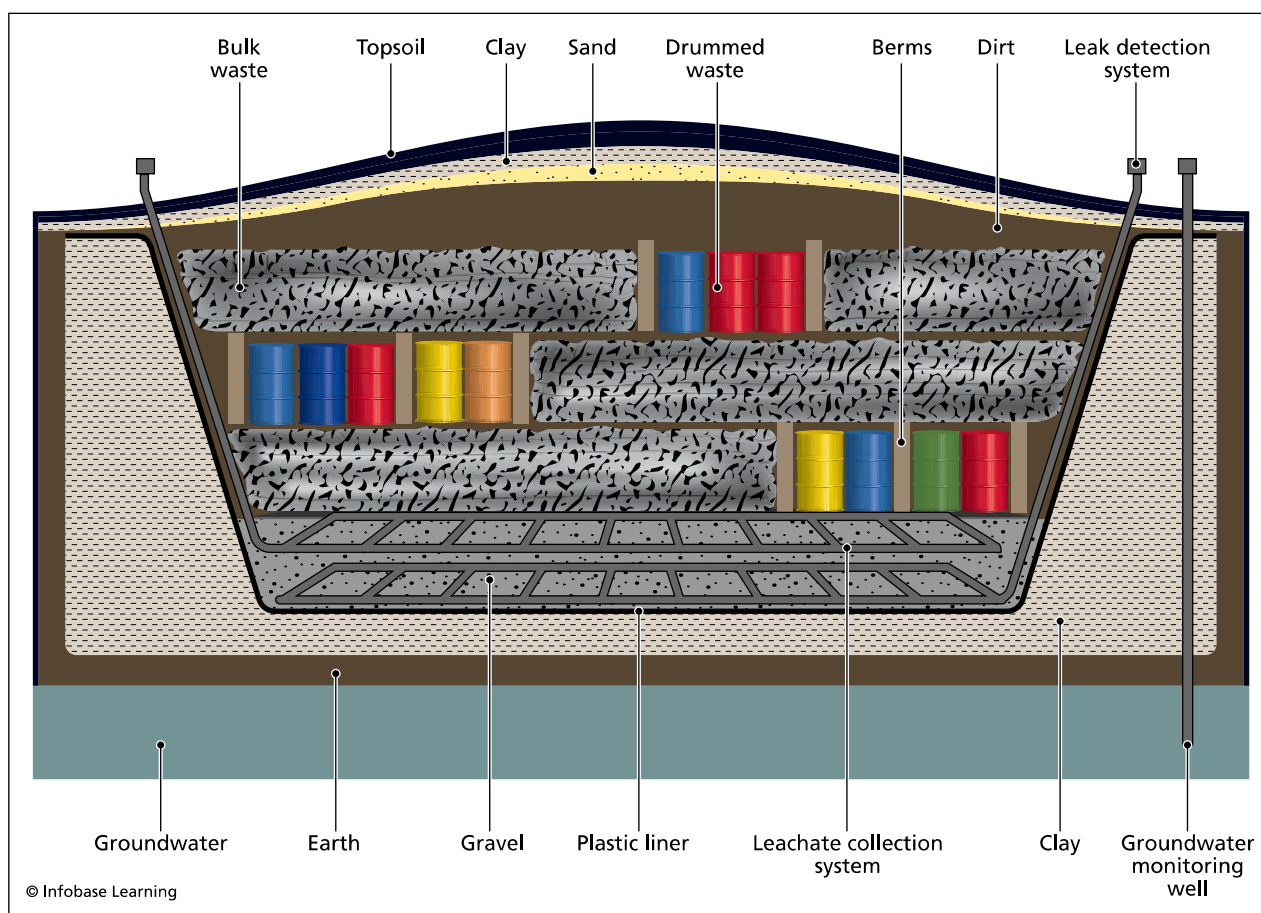


as landfill sites. Limestone, for example, develops karst topography, which includes cave systems, the roofs of which can collapse into a sinkhole. If a sinkhole forms beneath the landfill and collapses, the results could be disastrous, especially if in a hazardous waste landfill. Water supplies in the area could be severely damaged. Unfortunately, in some areas, Florida, for example, there is no choice but to site landfills on limestone.

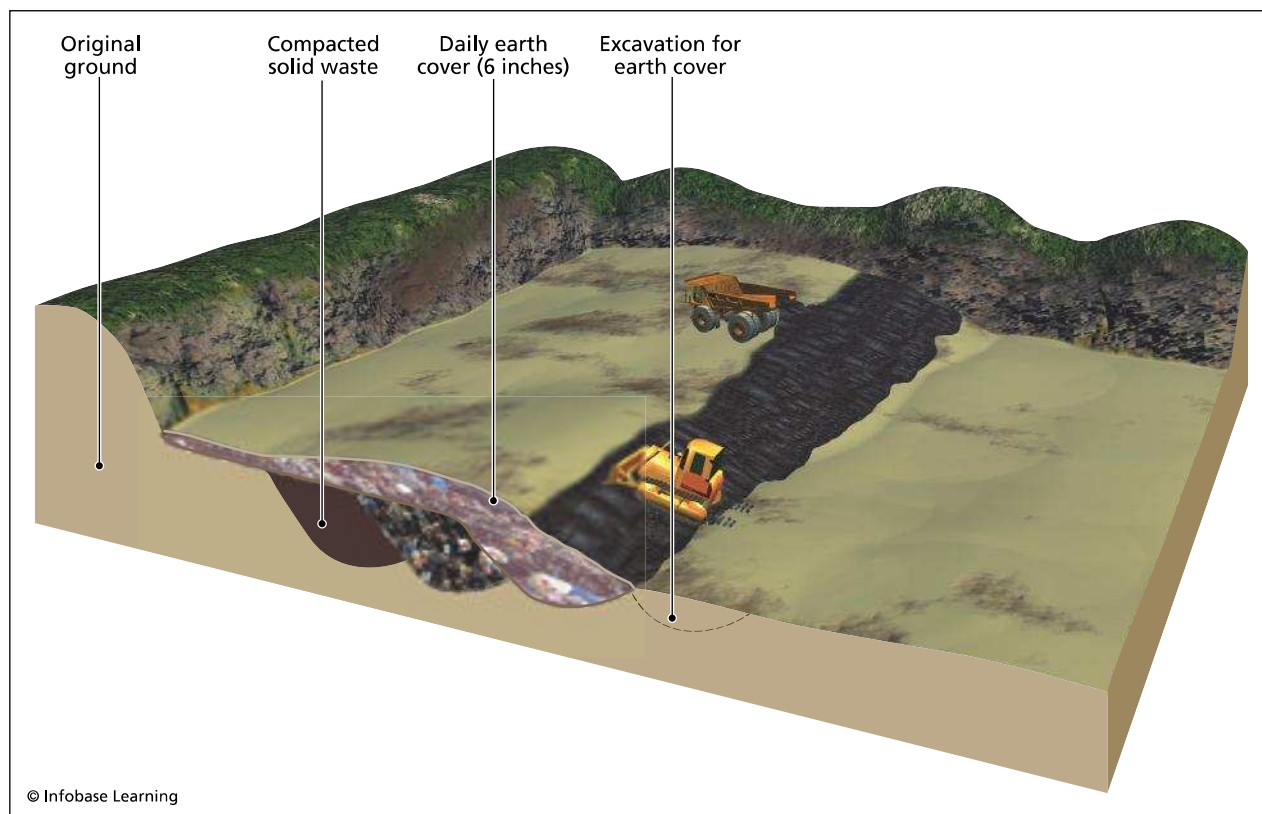
### MUNICIPAL LANDFILLS

Most cities operate municipal landfills to dispose of their solid waste. By 1996, 60 percent of all solid waste was disposed of in landfills, while 20 percent was incinerated, and 15 percent was recycled. At that point, there were 75,000 on-site industrial landfills, 5,800 municipal landfills, and more than 40,000 abandoned municipal landfills. In municipal landfills, solid waste is dumped into an excavated opening or pit that is lined with a chemically resistant plastic or rubber liner and compacted

by heavy equipment before it is covered with a minimum 6-inch (10-cm) thickness of dirt on a daily basis. Collection pipes are installed below and above the landfill to remove leachate in some, while others are judged to require being underlain by soil and rock to purify the water sufficiently before it enters the water table. Another sheet and/or a thick impermeable clay cap covers the landfill after it is full to prevent the infiltration of rainwater from above. Infiltrating rainwater could dissolve the waste to form leachate that could enter the groundwater system through a leak in the liner, or, if it filled up with water, it could overflow. The surface is formed into a mound to drain runoff away from the landfill, and a final soil cover of 24-inch (40-cm) thickness, which is covered with vegetation to stabilize the soil and slope, absorbs minor rainfall. Vertical wells are drilled into the landfill, and pipes are installed to vent methane gas produced by biogenic decay of the organic waste. Some communities mine the methane and sell it to local utility companies. Finally, monitoring wells



**Illustration of a secure landfill for toxic and hazardous waste: Drums of waste are kept upright and intact, and an extensive full-time monitoring system ensures against leaks.**



**Illustration of municipal sanitary landfill methods in which waste is covered with soil on a daily basis, ultimately filling an excavated pit**

are drilled around the landfills to test the quality of groundwater on a regular basis. If raw leachate reaches the water table, it can contaminate the local water supply with both pollutants and disease.

### HAZARDOUS WASTE LANDFILL

Disposal of hazardous waste is much more highly regulated than disposal of municipal waste. Landfills for hazardous waste must be lined with a thick, chemically resistant, and impermeable geotextile-plastic liner, thus preventing any leachate from escaping. All leachate is removed from the base of and below the landfill by means of a collection pipe to a storage and/or treatment facility. Hazardous waste is not compacted but, instead, carefully placed in the landfill and lined top and bottom. Rock and gravel are used to stabilize the waste to prevent it from being knocked over or crushed by overlying layers. The top is similar to that of the municipal landfill but must include an impermeable sheet, as well as a thick clay cap. There are typically more monitoring wells in a hazardous waste landfill, and they are sampled on a much more frequent basis. Hazardous landfills are built to last tens to hundreds of years.

Hazardous waste landfills can be filled with industrial chemicals, pesticides, some radioactive waste, some biological waste, and, in some cases, military refuse. The materials are deemed extremely dangerous to both human health and the environment and are highly regulated. In some cases, they are regulated on a national security level. These are commonly disposed of separately from commercially produced chemicals. Even the placement of the materials into the landfill must be performed under strict guidelines with proper tolerances and with workers' wearing specified protective clothing.

*See also* GROUNDWATER; LEACHATE; PESTICIDES; RADIOACTIVE WASTE; SOIL; WELLS.

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**Launch Complex 34 Cape Canaveral, Florida 1961–1971 Soil Pollution** Construction began on Launch Complex 34 in Cape Canaveral, Florida, in June 1959, and the facility was placed into service January 1962. Four *Saturn I* and *Saturn IB* rockets were tested and launched from this complex between 1961 and 1968, and it supported the Apollo and Skylab space vehicle programs. One of the more unique launches that took place from Launch Complex 34 was an experiment known as Project Highwater. The primary objective for this launch was to assess how liquid fuel would behave during lift-

off and orbiting maneuvers. Some 23,000 gallons (87,065 L) of water was loaded onto dummy second- and third-stage rocket boosters, and National Aeronautics and Space Administration (NASA) engineers and designers gathered important data on how the liquid payload shifted and moved during launch. At the height of its flight, 104 miles (167.4 km) above the Earth, the rocket was detonated and released the water into the ionosphere. Scientists had hoped to gain information on the formation of clouds and ice particles at this altitude, but a malfunctioning telemetry system made the data unreliable.

*Apollo 7*, the first manned Apollo flight, lifted off from Launch Complex 34 at Cape Kennedy on October 11, 1968. Launch Complex 34 also is where, on January 27, 1967, the tragic *Apollo 1* fire took the lives of three other Apollo program astronauts. Launch Complex 34 was decommissioned in 1971 but, because of its prominent role in the space program, was declared a national historic landmark in 1984 and is a popular stop on the Cape Canaveral bus tour.

### POLLUTION OF THE SITE

Cleaning and degreasing of precision equipment associated with space flight required the use of extensive amounts of chlorinated solvents. During the 1960s and continuing until the advent of modern environmental management practices in the late 1970s and early 1980s, spent solvents from these operations, primarily trichloroethene (TCE), were often inadvertently and sometimes intentionally discarded or spilled directly onto the soil on and around the launch complex. At Launch Complex 34, the spent TCE was discharged into drainage pits or onto the ground, both near the launch pad and from the Engineering Support Building (ESB). Since then, an estimated 45,000 pounds (20,412 kg) of TCE has migrated into approximately 6 million cubic yards (4.6 million m<sup>3</sup>) of soil at the launch complex and is contaminating the underlying groundwater.

Like many industrial solvents, TCE and its breakdown products 1,2 dichloroethylene (DCE) and vinyl chloride are less viscous and have a density greater than water. If released into the environment, they tend to move downward through the soil and groundwater, coming to rest on layers of low-permeability silt and clay or rock. This subsurface layer or pool of accumulated TCE is a type of dense nonaqueous-phase liquid (DNAPL). DNAPL is very difficult to locate and remediate, as its presence is controlled not so much by the groundwater flow system near where it was released, but rather through variations in subsurface soil conditions, such as porosity, permeability, and layering, which can be



**Injection of potassium permanganate into contaminated groundwater at Launch Complex 34, Cape Canaveral Air Station (NASA)**



difficult to predict and locate. DNAPL can act as a source of groundwater contamination for many years after its release has occurred, slowly dissolving into the water of the aquifer.

Another environmentally challenging characteristic of this compound is that it does not readily biodegrade. The very large size of the TCE molecule and the presence of chlorine tend to inhibit bacterial breakdown and allow TCE to persist in the environment for long periods. Also, TCE does not tend to attach to organic matter that may be present in the subsurface. This means that TCE will migrate at about the same rate as groundwater, whereas other contaminants often move much more slowly through the subsurface. TCE is toxic and, if inhaled, affects the central nervous system, causing dizziness and drowsiness and, at high concentrations, potential fatalities. The U.S. Environmental Protection Agency (EPA) has classified TCE as a probable human carcinogen. Ingestion of large amounts of TCE may lead to liver damage, kidney malfunction, and cardiac arrhythmia. Similar health effects have been observed from exposure to DCE and vinyl chloride.

### THE CLEANUP

TCE was found in the soil of Launch Complex 34 at concentrations up to about 0.03 percent (30,000 mg/kg), essentially present as a separate phase or DNAPL. TCE cleanup is complicated by two factors, the role Launch Complex 34 (LC-34) has had in the history of the space program and the need not to interfere with other, nearby NASA activities. It is a designated historic structure, and remediation must be carried out in a way that minimizes changes to the characteristics of the building, the site, and the local environment. This means that remediation cannot destroy historic materials, and chemical or physical techniques such as sand-blasting or large-scale excavation that might damage the historic materials cannot be used. In addition, although NASA is no longer using LC-34 for flight operations, the surrounding area is an active spaceport, and remedial actions cannot interfere with access to the area. In situ chemical oxidation using potassium permanganate was one of the technologies chosen by NASA, in cooperation with the state of Florida and the EPA, to clean up this contamination within the context of the site.

In situ chemical oxidation is a remedial process that introduces an oxidant into the subsurface to break down or convert the contamination into a more stable, less toxic form through oxidation. In this process, oxygen removes electrons from other atoms. This tendency is so strong that it has led chemists to name any process that entails the loss of electrons from an

atom or ion oxidation, even those that do not involve oxygen. In terms of environmental remediation, if an oxidizing agent is mixed with the contaminant in soil, then the subsequent chemical recombinations that take place as electrons are removed by the oxidant would destroy or break down the contaminant. In practice, the contaminants are actually converted to more stable, less mobile, or inert compounds or readily biodegradable organic fragments. The three most common chemical oxidants used in soil remediation are ozone, peroxide, and permanganate.

Ozone ( $O_3$ ) is a very aggressive oxidant. If ozone is introduced into the vadose zone as a gas, it reacts quickly with the contaminant mass. The contaminant, usually a petroleum hydrocarbon, is converted to carbon dioxide and water or is broken down into carbon and other compounds that surrounding bacteria can utilize. A liquid peroxide solution can also be used to initiate chemical oxidation in the subsurface to remediate polluted soil. Typically, the peroxide is introduced in a water mixture through specially designed injection wells. In order to accelerate the peroxide's chemical oxidation effectiveness, a metal catalyst, most commonly iron, is added. This peroxide and iron mixture is known as Fenton's reagent. The hydroxyl radicals are strong oxidizing agents, capable of rapidly attacking and breaking the carbon chemical bonds of most organic compounds, usually within minutes after its application. As in ozone-induced chemical oxidation,  $O_2$  is released during peroxide decomposition and can help encourage bioremediation.

Permanganate can oxidize contaminants under a wide range of pH (3.5–12) and does not require a catalyst. Its oxidation potential is lower than that of Fenton's reagent by about 40 percent, and, therefore, permanganate requires more time to act. Potassium permanganate ( $KMnO_4$ ) is most commonly used, but Na, Ca, or Mg varieties are also available. The main advantage of permanganate is that it is not as reactive as ozone or Fenton's reagent. The permanganate can move deep into the contaminant mass, especially in low-permeability formations such as clay or silt, and contact a larger amount of impacted soil. Permanganates are also more easily handled and, because of their high solubility, simpler to mix and inject into the subsurface.

The permanganate ion is preferentially drawn toward the electrons in carbon-carbon double bonds found in compounds called alkenes. Examples of alkenes include trichloroethylene (TCE) and tetrachloroethylene (PCE). The permanganate breaks down the double carbon bonds by borrowing the electrons from the carbon atoms. Once the double bonds are broken, the unstable fragments are converted to carbon dioxide through



## Space Shuttle Launches and Air Pollution

The Saturn V rocket, the largest ever built and operated by the National Aeronautics and Space Administration (NASA), successfully launched the Apollo Moon missions and the Skylab Space Station, and it continues to lift the space shuttle into orbit around the Earth. When the fuel in the Saturn V is ignited, it forces a massive, continuous thrust of hot gases downward through its vents and portals. This downward force results in an equal and opposite push of the rocket upward. Current space vehicles operate on a linear, multistage design. A single-stage-to-orbit (SSTO) vehicle that is being evaluated by NASA can achieve orbit without discarding fuel tanks or motors. SSTO vehicles, which also would be reusable, may be less expensive to launch and operate, although more expensive to design and build.

### TYPES OF ROCKET FUEL

The rockets and their fuels are stacked on top of each other, with the first stage the largest and having the heaviest fuel. When the first-stage rocket's fuel is exhausted, it is detached with a small explosive charge from the space vehicle, and the second-stage rocket is fired. After the second-stage rocket's fuel is used up, the third stage is fired, and so on. By jettisoning the empty fuel tanks and associated rocket motors, the now much lighter spacecraft requires less fuel to reach its mission or orbital velocity and altitude. In addition, fuel selection can be optimized for its operational atmosphere.

The power, efficiency, and environmental impact associated with the use of rocket fuel are dependent upon its chemical composition. NASA, the military, and commercial launch organizations generally rely on four types of propellants:

#### Petroleum

This type of rocket fuel is highly refined kerosene called RP-1 (refined petroleum). Rocket fuels need to provide their own oxidizer, and RP-1 is usually combined with liquid oxygen (LOx) and burned to create thrust at low altitudes. RP-1 is a fossil fuel, and its combustion products include carbon dioxide, sulfur and nitrogen oxides, and particulate matter.

#### Cryogenics

These types of propellants are a mixture of fuel of liquid hydrogen (LH<sub>2</sub>) and liquid oxygen. Both components are liquid at only very low temperatures (hundreds of degrees below zero), but cooling and compressing them

allow large amounts to be stored in appropriately sized containers. If they were left in their gaseous forms, huge fuel tanks would be needed to store sufficient amounts of hydrogen and oxygen to launch a spacecraft or missile. Cryogenic fuels are lighter and have about 40 percent more power by weight than petroleum or solid rocket fuels. The Saturn V second- and third-stage rockets are cryogenically fired and are used to insert the space shuttle into Earth orbit. The end product of this combustion process is water, making cryogenic fuel very environmentally friendly.

#### Hypergolics

Thrust from this type of propellant occurs as fuel of monomethyl hydrazine (MMH), or hydrazine, and oxidizer of nitrogen tetroxide (N<sub>2</sub>O<sub>4</sub>) ignite during mixing, requiring no ignition source. One of the major advantages of hypergolics is that they can be stored at ambient temperatures and pressures, and the reaction can be started and stopped by simply shutting off the flow of either the oxidizer or the fuel. MMH and N<sub>2</sub>O<sub>4</sub>, however, are dangerously toxic and must be managed by using highly controlled safety procedures. Hypergolics power the space shuttle's orbital maneuvering, attitude control, and reentry systems.

#### Solids

Also called solid rocket boosters (SRB), these are the oldest type of rocket fuel, first developed in ancient China. Fuel and oxidizer are loaded into a steel shell and ignited to provide thrust. For the Space Shuttle, the oxidizer is ammonium perchlorate, and the fuel is a form of powdered aluminum. A third ingredient, polybutadiene acrylic acid acrylonitrile, binds the mixture. Initially a liquid, SRB is cured into a soft, rubberlike solid. Stable and easily stored, SRBs do not require complex propellant-feed systems and often are used to provide additional thrust during launch or during the final stages of a launch. The space shuttle uses the largest solid rocket motors ever built, with each reusable booster containing more than 1 million pounds (454,000 kg) of propellant, supplying almost 2.7 million pounds (1.2 million kg) of thrust. The majority of military rockets (intercontinental ballistic missiles [ICBMs] such as the Minuteman and Peacekeeper) also use solid rocket fuels.

### ENVIRONMENTAL EFFECTS OF ROCKET LAUNCHES

Space shuttle launches as well as other types of space exploration or military rocket testing and develop-

ment produce adverse environmental effects. Most of the emissions that are seen during a space shuttle launch are water vapor or steam mixed with very minor amounts of combustion products. At 11 seconds before the main engines fire, a storage tower near the launch pad begins to discharge about 900,000 gallons (3.4 million L) of water from six large nozzles, called rainbirds, into a trench just beneath the launch pad. This water continues to flow for about 20 seconds after main engine ignition and acts as an acoustical barrier and flame deflector, protecting the shuttle from the noise and heat generated by the SRBs during a launch.

The exhaust gases from the SRBs, which provide about 70 percent of the launch thrust for the space shuttle, contain very small amounts of chlorine. This chlorine combines with water vapor to form hydrochloric acid mist, which has caused some damage to wetlands and plants near the launch pad. NASA tries to mitigate these effects by launching when local winds blow this mist out to sea, where it is quickly neutralized by seawater.

As the space shuttle climbs into orbit, exhaust gases released into the thermosphere, the outermost layer of the Earth's atmosphere, settle and condense into a cloudlike layer of ice crystals. This layer, which has been detected in the sky over the Arctic, results in a "night-shining," or noctilucent, cloud, one that is not visible until the Sun's rays reflect off it from below the horizon. Although this small amount of additional water vapor is not likely to have an impact on either arctic or worldwide atmospheric conditions, its presence is illustrative of the need to be alert to the environmental consequences of rocket launches.

Of more immediate concern is perchlorate, one of the primary components of SRB fuel. Perchlorate has been detected in groundwater and soil samples from more than 40 states. If ingested, perchlorate interferes with iodine uptake in the fetus, young children, and adults. The U.S. Environmental Protection Agency (EPA) is currently considering adding perchlorate to the list of chemicals that must be tested under the Safe Drinking Water Act. California, Arizona, Nevada, and other states that have hosted significant amounts of rocket tests and launches are especially concerned over the presence of this compound in their local environments and perchlorate's potential impact on public health.

On a global scale, about 11,000 tons (10,000 metric tons) of rocket propellant is burned in the atmosphere annually from both civilian and military sources. The release of chlorine, free radicals, and aerosols as a result of these launches, particularly those using SRB

and hypergolic fuels, may damage the ozone layer. Although the amounts of potentially ozone depleting substances released by this activity are relatively small on an international scale, approximately 130,000 tons (117,900 metric tons) of ozone-depleting products was manufactured worldwide in 2003. They are, therefore, not insignificant, and part is delivered directly to the stratosphere, where they do the most damage.

The technologies to launch rockets into space were developed at a time when political and military agendas were the driving forces. Technological dominance over the Soviet Union far outweighed the environmental consequences on the American agenda. Those attitudes have changed in recent years, and space exploration is becoming more environmentally responsible. Environmental Impact Statements are required before a new or expanded launch program can be initiated, and these programs must include measures to reduce or minimize ecological and atmospheric effects. Extensive research is being done to find a cheaper, safer, and less environmentally damaging replacement for hydrazine-driven thrusters. Ion engines and electric propulsion systems are the leading candidates, along with short-term fuel combination changes that provide some environmental benefit from the more efficient mixing and matching of propellant types.

*See also* AIR POLLUTION; OZONE AND CHLOROFLUOROCARBONS; PERCHLORATE.

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—by Robert P. Blauvelt

either hydrolysis—decomposition that occurs when water molecules are taken up into the fragment—or further oxidation by the permanganate ion.

Regardless of which oxidant is used, it must be chosen on the basis of the type and extent of contamination as well as cleanup goals and overall site conditions. All the compounds are very reactive and must be handled with great care to prevent injury to workers or nearby residents. Oxidants by their nature are corrosive and can wear away or dissolve dispensing equipment. Site-specific procedures for their safe distribution must be developed and strictly followed. Chemical oxidation can generate enough heat to boil water, so in some cases provisions must be made to collect and treat the gases that may be given off by the process. Hazardous intermediate compounds can form if not enough oxidant is added to the contaminant mass or if other compounds in the soil such as organic matter consume the oxidant before it can completely react with the contaminant. These issues aside, chemical oxidation is rapidly gaining favor as a remedial technology because it can efficiently reach and clean up contaminated soil in time frames much shorter than many other methods required.

At LC-34, the area of contaminated soil to be treated was divided into a cell 50 feet (15.2 m) wide by 75 feet (22.9 m) long by 45 feet (13.7 m) deep. Samples collected within that area indicated that an estimated 13,420 pounds (6,100 kg) of TCE was confined to three soil layers: an upper sand unit; a middle, fine-grained sand unit; and a lower sand unit. In order to develop final design parameters, a pilot test using a tracer solution (sodium fluoride) mixed with 2 percent permanganate was first tried. This test allowed the design engineers to obtain data on the way the permanganate solution would move through and react with the contaminant mass. The full-scale treatment program utilized 19 injection wells, which were driven into the various layers within the designated treatment zone or cell, and more than 150,000 pounds (68,039 kg) of permanganate at concentrations ranging from 0.2 to 3 percent was injected in three phases over 61 days.

After treatment, soil samples were collected from each of the three layers, and TCE levels were tested. Posttreatment soil sampling data indicated that the mass of TCE within the cell had declined by 82 percent.

*See also* DCE; GROUNDWATER; IN SITU GROUNDWATER REMEDIATION; TCE; VINYL CHLORIDE; WATER POLLUTION; WELLS.

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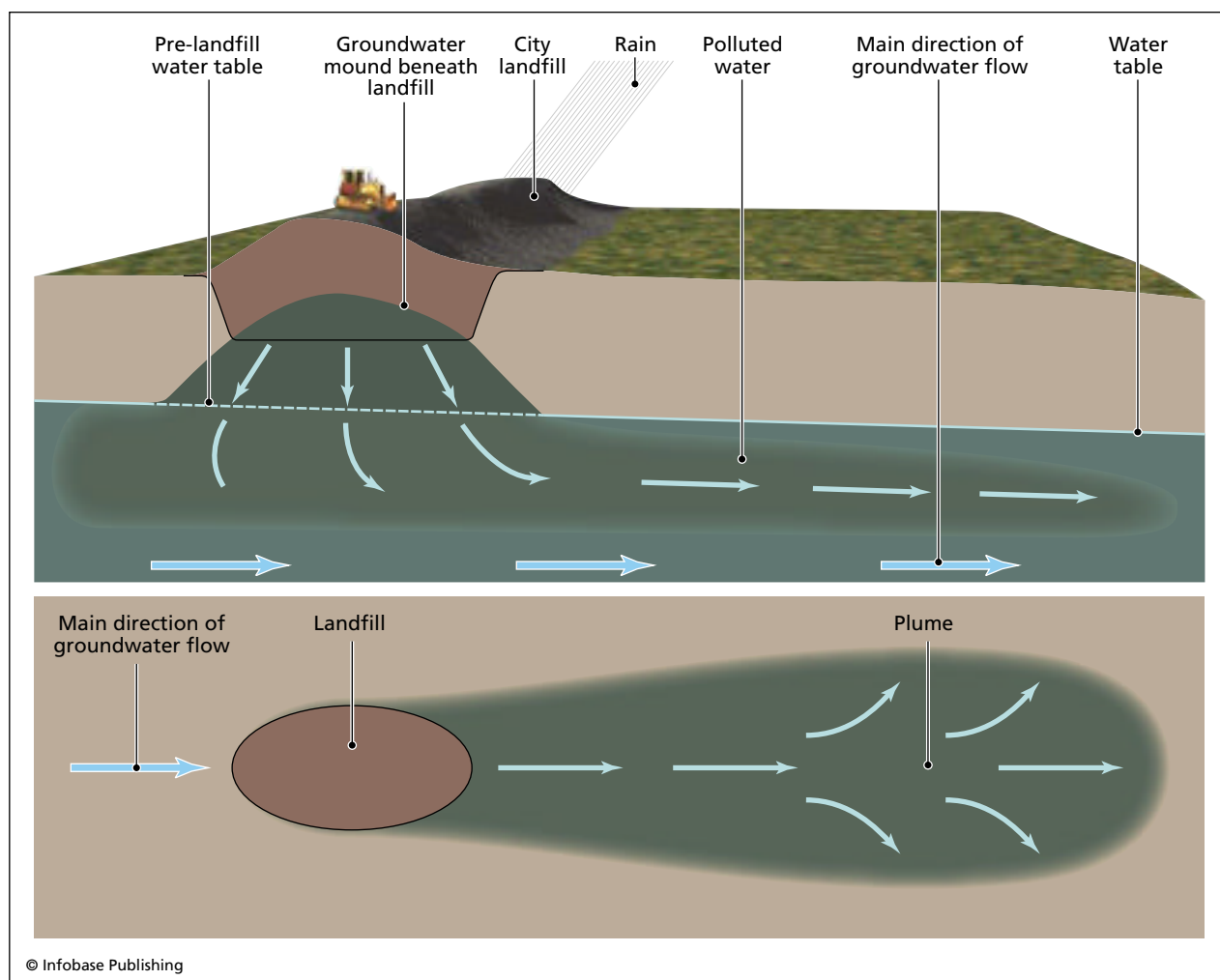
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**leachate** Fluid rich in by-products of the decomposition and dissolution of municipal and/or toxic waste is generically termed leachate. The putrid, foul-smelling liquid that drips from the back of a garbage truck is analogous to leachate but typically far less dangerous than landfill leachate. Any fluids that are emitted by waste, whether by infiltration and dissolution or directly derived from the waste, is leachate. The toxicity of leachate depends upon the type of waste involved. Hazardous waste landfills produce much more dangerous leachate than municipal landfills. Pipes are carefully installed into landfills to remove the fluids from the bottom. They are then put through an ex situ remediation process and returned to the groundwater system or removed completely, depending upon the toxicity.

If leachate enters the groundwater system through a hole in the bottom of a landfill, it can severely degrade the quality of the groundwater. In this case, a full-scale remediation project must be initiated. This involves the drilling of monitoring and recovery wells and construction of water treatment facilities at significant cost. Depending upon the waste in the landfill, patching the liner or removing waste may have to be performed as well. Although leachate may contain inorganic pollutants, it is primarily a biological process that produces organic waste.

#### FORMATION OF LEACHATE

There are three stages in the formation of leachate from municipal sanitary landfills, which are by far the major source of leachate. The first stage is aerobic decomposition, in which all of the available oxygen present in the waste is consumed. These chemical reactions are exothermic, and the temperature of the landfill increases. The second stage in this process is called the acetogenic stage. Anaerobic bacteria break down the waste by fermentation of sugars to acetic and other volatile fatty acids. Car-



**Cross-sectional (top) and map (bottom) view of a leaking landfill producing leachate that enters the groundwater system and forms a contaminant plume spreading in the direction of groundwater flow**

bon dioxide and hydrogen gas are produced, and alkalinity of the fluid is greatly increased. Later, sulfate-reducing bacteria cause biodegradation of the fatty organic acids. The formation of acids causes dissolution of waste materials and increases the content of inorganic pollutants in the leachate. The final stage in leachate evolution is called the methanogenic stage. After all the sulfate is consumed, microorganisms that produce methane and carbon dioxide from volatile fatty acids and other organics become dominant. In this stage, methane can be mined from the landfill for commercial uses. Eventually, the decomposition rates decrease as the amount of available organic material decreases and the landfill slowly becomes inactive.

Leachate composition varies considerably depending upon the type of waste, age of the landfill, climate, precipitation, integrity of seals, and other factors. The organic content of the leachate is expressed in

BOD (biochemical oxygen demand) and COD (chemical oxygen demand). These parameters reflect the amount of oxygen needed to oxidize the organic matter by microbial biodegradation (BOD) and chemical oxidant (COD).

*See also* CARBON DIOXIDE; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; ORGANIC POLLUTANTS; WELLS.

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**lead** Lead is an inorganic heavy metal that is consistently one of the pollutants of greatest concern in modern society. On the 2007 CERCLA Priority List of Hazardous Substances, lead is ranked the second most dangerous pollutant, with only arsenic ranked higher. It is not only the severe adverse health effects caused by lead but also its immense distribution in the environment that gives it such a high ranking. For example, lead has been found in at least 1,272 of the first 1,684 U.S. Environmental Protection Agency (EPA)-designated Superfund sites on the National Priority List. This is probably the highest percentage of any of the dangerous pollutants.

Considering the vast usage of lead in society into the 1970s, it is surprising that it is now so vilified. Lead was used as a gasoline additive, as a paint additive, in virtually all plumbing (the term *plumber* means “worker of lead”), in all automotive batteries, in all bullets and other projectiles, and in many electric and electronic devices among many other uses. Through all these applications there was barely an American who was not exposed to lead in a significant way, and the ambient levels of lead that people were exposed to on a daily basis were orders of magnitude above natural background levels. Perhaps even more surprising is that historical examples suggest that people knew that lead has detrimental effects. One of the often-cited contributing factors to the fall of the Roman Empire was the excessive use of lead in plumbing and food. Lead poisoning on a societal level may have so weakened the health of the citizenry that they were unable to defend themselves against attack.

### PROPERTIES, USES, AND PRODUCTION

Lead is a naturally occurring inorganic element commonly found in minerals, soils, and mineral deposits throughout the world. In the United States, currently some 88 percent of all lead is mined from seven mines in the New Lead Belt of southeastern Missouri. There is a long and varied history of lead use in the United States. The earliest widespread

use of lead that affected the environment may have been in paint, beginning in the early 19th century, when lead carbonate or “white lead” was used as the paint pigment and primary component, right through the 1960s. Before 1955, lead constituted up to 50 percent of the volume of white paint but the level was voluntarily reduced by some manufacturers thereafter. Lead orthoplumbate and lead oxide, or “red lead,” were used as red, pink, and orange pigment, most commonly for primers, also through the 1960s. In houses built before 1978, some 83–86 percent contain lead paint. Ever since there was indoor plumbing, lead has been used as solder and even in pipes in the past. In the 1920s, as cars began to become more sophisticated, lead was used as an additive to gasoline to boost octane and prevent knocking. It became by far the greatest source of lead emissions, providing up to 90 percent of environmental exposure in many areas. Lead is currently the fifth most consumed metal in the United States. Approximately 85 percent of lead is produced domestically and 40–50 percent is from recovery and recycling efforts. The United States is the world leader in lead recycling efforts. In 2006, mine production was 473,000 tons (430,000 metric tons), and the five-year average is 486,600 tons (442,400 metric tons). Primary lead from refineries was 148,500 tons (135,000 metric tons), which indicated a steady decrease from 2002, when production was 288,200 tons (262,000 metric tons). Scrap recycling produced 1.24 million tons (1.13 million metric tons) of lead in 2006. The two most important consumers of lead are lead-battery producers and radiation shield producers. Lead-acid batteries account for 83 percent of the consumption. Other uses in outdoor sports and recreation, hobbies, and wheel balancing weights are minor.

### ENVIRONMENTAL RELEASE AND FATE

Currently, sources of environmental lead include both industry in localized areas and widespread residential sources. Some 144 million pounds (65.5 million kg) of industrial lead was released into the environment from 1987 to 1993, primarily from lead and copper smelting and steelworks; lesser sources include batteries, plumbing fixtures, iron foundries, and copper mining. The states with the highest releases are, in decreasing order, Missouri, Arizona, Montana, Utah, Texas, Ohio, Indiana, Tennessee, Illinois, Wisconsin, Minnesota, and New Mexico. Only Ohio and Indiana had significant releases into surface water. Much more widespread sources of environmental lead are corrosion of lead plumbing (especially in older homes), both

interior and exterior peeling paint in older homes, paint-tainted soil surrounding older homes, glazing on ceramic stoneware, dyed and printed paper and incineration thereof, and aluminum cookware from countries lacking environmental controls. Many hobbies and household chores can also expose people to lead including hunting and fishing (shot and sinkers), home renovation (paint, pipes), furniture refinishing, ceramics and pottery, glass work (leaded glass, stained glass), and auto restoration, among others. Other minor sources of lead exposure are the consumption of vegetables grown in lead-tainted soils, wine and some alcohol, and cigarette smoking.

Most lead in the environment is from atmospheric sources and settles to the ground and surface water as nonpoint source pollution. It binds tightly to soils in the upper 1 to 2.5 inches (2–5 cm) and does not migrate to groundwater under typical conditions ( $> 5$  percent organics,  $\text{pH} > 5$ ). Remediation of soil is typically accomplished by removal. In the subsurface, some anaerobic microbial activity may be a significant source of dissolution, thereby increasing the lead content of groundwater. Metallic lead exposed at the surface

is degraded by oxidation and hydration, but, under certain conditions, silicate and carbonate films can protect it from chemical alteration. It can contaminate surface water but tends to bind to clay and organic particles, ultimately settling into the sediments. Some microorganisms in lake sediments can methylate some inorganic lead compounds. Highly acidic surface waters and groundwaters can contain significant amounts of lead, and methylation can also increase concentrations. Dredge spoils can also be contaminated with lead. There is little bioaccumulation of lead in fish (bioconcentration factor 1.65), and it does not accumulate in the edible parts of the fish, but shellfish can contain lead (bioconcentration factor 3.4).

### HEALTH EFFECTS FROM EXPOSURE

Acute lead poisoning results in nausea, sluggishness, vomiting, painful gastrointestinal irritation, diarrhea, loss of appetite, colic, weakness, dehydration, discoloration of the lips and skin, convulsions, external limb paralysis, coma, and death with increasing exposure. Chronic exposure to lead results in numerous adverse physiologic effects including



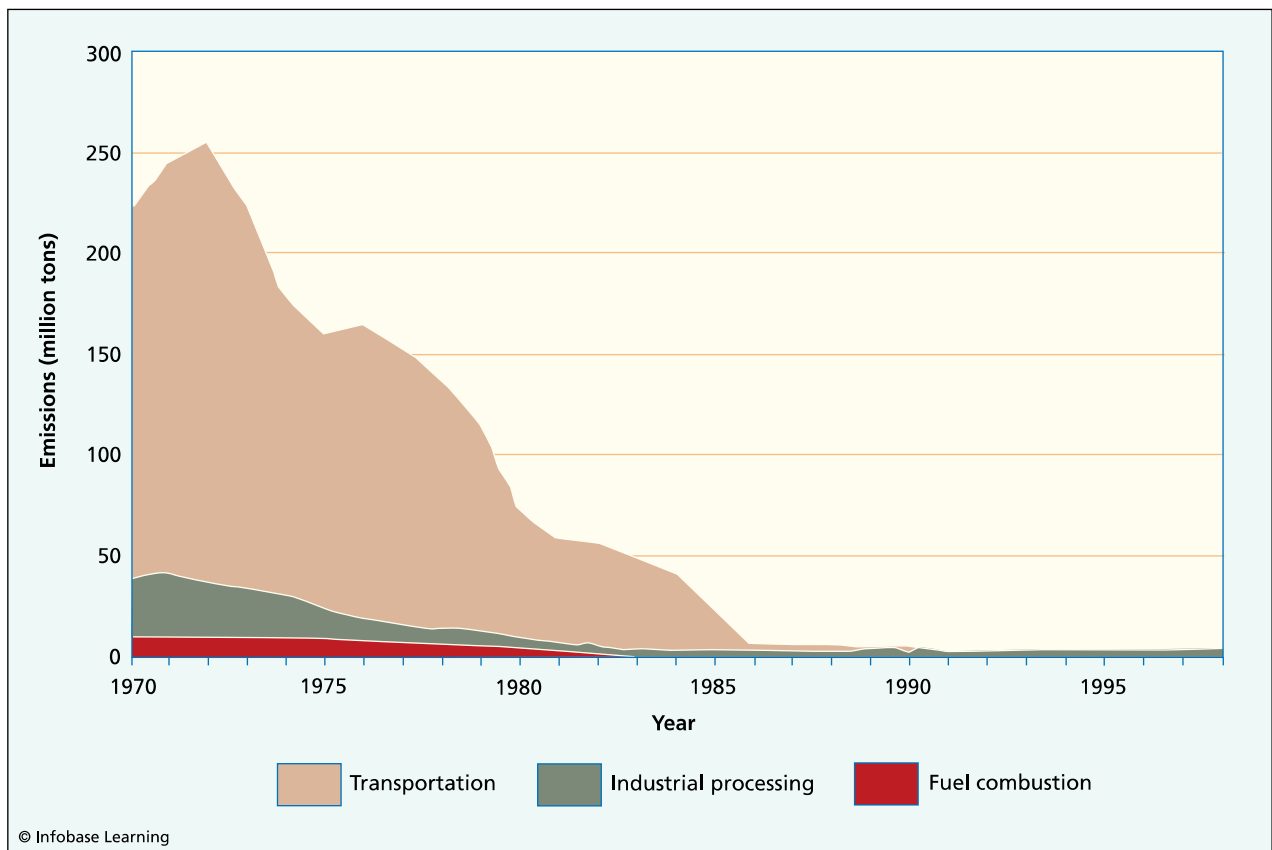
Peeling lead paint at abandoned mental institution in Traverse City, Michigan, 2004 (© Robert Sciarrino/Star Ledger/Corbis)

neurological effects, renal damage, hematological problems, endocrine effects, cardiovascular and hypertension effects, reproductive effects, developmental problems, and cancer. The health effects of lead exposure in children are so devastating that the Center for Disease Control established a class system of poisoning with recommended treatments. The nervous system is the primary area of damage from lead, and children are much more readily affected than adults. Symptoms include lower than average IQ test scores, attention deficit hyperactivity disorder (ADHD), muscular tremor and weakness, loss of memory, depression and mood swings, decreased reaction time, irritability, decreased hand-eye coordination, hearing impairment, and early onset of Alzheimer's disease. Lead also readily affects the kidneys, resulting in impairment of proximal tubular function, chronic nephropathy, gout, and ultimately kidney failure if not treated. By inhibiting several enzymes in the blood, lead can decrease hemoglobin, cause anemia, and impact overlapping systems. Lead impedes the conversion of vitamin D to its hormonal counterpart, thereby negatively affecting several important processes including cell

growth and maturation and bone and tooth development. The cardiovascular effect of lead exposure is a significant increase in blood pressure, which can adversely affect other organs. The effects of lead exposure on reproduction and development include decreased sperm count and quality, possible stillbirths and miscarriages, premature births and low birth weights, increased congenital abnormalities, and other birth defects. Although lead has not been proven to cause cancer, the National Toxicology Program has categorized lead as "reasonably anticipated" to be a carcinogen.

### REGULATIONS ON HUMAN EXPOSURE

The Lead Contamination Control Act of 1988 severely curtailed the release of environmental lead. The EPA has been regulating lead in water under the Safe Drinking Water Act for many years, establishing a 15 parts per billion (ppb) threshold for remedial action with a goal of zero lead in water. The EPA further requires that lead concentration in air in public spaces be no higher than 1.5 micrograms per cubic meter. If one pound (0.45 kg) of lead



**Graph of total emissions of lead separated by source versus time. Lead emissions reached their peak in 1972 but declined rapidly after it was restricted and banned to minimal levels by 1986, where it has remained ever since.**



arsenate or 10 pounds (4.5 kg) or more of metallic lead, lead acetate, lead chloride, lead fluoborate, lead fluoride, lead iodide, lead nitrate, lead phosphate, lead stearate, lead subacetate, lead sulfate, lead sulfide, lead thiocyanate, and tetraethyl lead is released to the environment, it must be reported to the National Response Center. The Occupational Safety and Health Administration (OSHA) limits lead in workplace air to 50 micrograms per cubic meter for an eight-hour-workday, 40-hour workweek. If the blood lead level of a worker reaches 50 micrograms per deciliter or higher, then the worker must be removed from the workroom. The National Institute of Occupational Safety and Health (NIOSH) set their designation of immediately dangerous to life and health (IDLH) to 100 micrograms per cubic meter for metallic lead and their recommended exposure limit (REL) to 0.050 microgram per cubic meter of metallic lead, lead oxides, and lead salts including organic salts such as lead soaps but excluding lead arsenate in workplace air for an eight-hour-workday, 40-hour workweek.

The good news about lead is that all of the efforts to reduce it in the environment seem to be working. Between 1987 and 1996 in the United States, lead emissions were reduced by 50 percent, and concentrations in ambient air decreased by 75 percent. In 1978, the number of children in the United States who had elevated blood lead levels numbered as much as 13.5 million. By 2002, the number had declined to about 310,000, and the decline has continued to the present. These impressive results are not only from legislative action but also mainly from a strong education and outreach campaign.

See also AIR POLLUTION; ARSENIC; INDOOR AIR POLLUTION; INORGANIC POLLUTANTS; CLAIRE CAMERON PATTERSON, "PAT"; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE.

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## London "Killer Fog" London, United Kingdom December 5–9, 1952 Air Pollution

Coal was a commonly used fuel in the 1950s in London, United Kingdom. It heated homes, cooked dinners, and fueled industrial furnaces and boilers, both in London and around the rest of Great Britain. Its connection to the frequent fogs as thick as "pea soup" was well known. In 1905, a London physician coined the term *smog* by combining the words *smoke* and *fog* to describe the way the high humidity in London combined with smoke from burning coal to form a particularly dense and long-lasting atmospheric pollutant. Today, the word *smog* has become synonymous with the haze or reduced visibility caused by many types of air pollution, not just that associated with burning coal. To be precise, recent usage requires the addition of a modifier that specifies the source of the smog. That described in 1905 is *London type*, or *classical*, smog and is formed by smoke or particulate as a primary air pollutant. In contrast, *Los Angeles*, or *photochemical*, smog is caused by atmospheric chemical reactions of petroleum hydrocarbons from automobile exhaust and sunlight and forms secondary air pollutants.



Midday smog in Piccadilly Circus, London, 1952 (Central Press/Hulton Archive/Getty Images)



Total suspended particulate (TSP), microscopic particles of dust with average diameters of less than 50 micrometers ( $\mu\text{m}$ ), was recognized early in the development of air pollution control laws as a significant threat to public health and the environment. If coal or any organic material is burned at a low temperature and without enough air, such as in a home stove or fireplace, it gives off smoke, a visible product of its incomplete combustion. Entrained in this smoke are a variety of hot gases and vapors as well as small carbonaceous particles that are carried up the chimney and are generally known as soot. The place that most typifies the need for control of particulate air pollution is the city of London, which has historically been filled with smoke and covered with soot.

If coarse TSP in the range of 10–50  $\mu\text{m}$  is deposited in the part of the respiratory system that is relatively self-cleaning including the nose, throat, and connecting airways that are lined with mucus, the short-term health impact is minimal. The particles are constantly flushed from these areas to the back of the throat, where they are swallowed and digested in the strong acids of the stomach. Usually within a few hours of exposure to TSP, the lungs and respiratory system have been cleared. For the normal healthy adult, short-term exposure to coarse particulate matter is a minor annoyance. It can lead to coughing, throat irritation, and a temporary reduction in lung function or, at worst, sinus infections.

If, however, children, elderly adults, or people who have existing heart or lung diseases, such as asthma; chronic obstructive pulmonary disease (COPD), including bronchitis or emphysema; congestive heart disease, in which heart muscles are too weak to pump blood efficiently; or ischemic heart disease with arteries blocked by cholesterol, are exposed to TSP, the self-cleaning mechanisms in their lungs are not strong enough to clear the particulate quickly. Individuals who have these and other types of medical conditions are not able to breathe normally and start to cough and are unable to catch their breath. Eventually, they may need to be admitted to hospital emergency rooms for treatment, and their risk of premature death from their preexisting heart or lung disease significantly increases.

In 1300, King Edward I banned, under penalty of death, the burning of coal because of the soot and odor it produced. This law was quickly rescinded as the forests around England's major cities began to disappear rapidly. For the next 600 years, England wrestled with ways to balance the need to run its economy, largely based on the burning of coal, and its need for clean air. London was especially suscep-

tible to the effects of burning coal. Only a few miles from the North Sea, the city's weather for much of the year was cold and damp. Particulate is able to stay suspended for long periods under these conditions and become very concentrated in the atmosphere by latching onto the water vapor present in this high-humidity environment.

### THE POLLUTION DISASTER

During the night of Friday, December 5, 1952, a layer of warm, moist air was trapped over the city by the beginnings of an unusually long-lasting temperature inversion. With little or no wind, particulate emitted by thousands of coal burning devices began to accumulate in the humid atmosphere. The fog thickened, and visibility dropped to a few feet. The stage was set for the great 1952 London Fog disaster, which was perhaps the worst air pollution disaster of all time. For the next 114 hours over five days, London was continuously shrouded in smog to the point where it became difficult for residents to tell night from day.

On Saturday, December 6, 1952, Londoners awoke to darkness. As they ventured outside, the pollution began to cause serious health problems, especially to the "at risk" population. The hospitals began to become overrun with patients. The ambulances stopped running as a result of the chaos and poor visibility, and thousands of gasping Londoners were forced to walk through the smog to the city's hospitals. In all, 500 people died in London that day of smog-related complications. Even animals suffered from the smog. Cattle in the city's Smithfield market fell over gasping and died, and their carcasses were simply thrown away before they could be slaughtered and sold.

By Sunday, December 7, visibility fell to one foot (30 cm). It was impossible to travel, because the roads were littered with abandoned cars. Midday concerts were cancelled because of the total darkness. Smog was infiltrating homes by then. Archivists at the British Museum noted smog in the book stacks. A theater had to be closed when fog inside the building forced patrons and performers to leave because they could not breathe. It was reported that in certain low-lying areas of London's East End, visibility was so poor that people could not see their own feet. This infiltration of smog into buildings began to cause adverse health effects for people who were not venturing outside. The steady stream of dying patients to hospitals continued. The lips of the dying were blue. Tobacco smoking and chronic exposure to pollution had already weakened the lungs of those most affected by the smog, triggering

massive inflammations. In essence, the dead, who numbered more than 750 this day, had suffocated.

Monday, December 8, and Tuesday, December 9, were no better. Road, rail, and air travel continued to be almost impossible. Conditions worsened and the death toll was estimated at 900 during each of those two days. Then late on December 9, the wind swept in unexpectedly, and the killer fog vanished as quickly as it had arrived, but the death of people affected by the smog continued for several weeks until just before Christmas. The mortality rate of bronchitis and pneumonia increased more than sevenfold as a result of the smog.

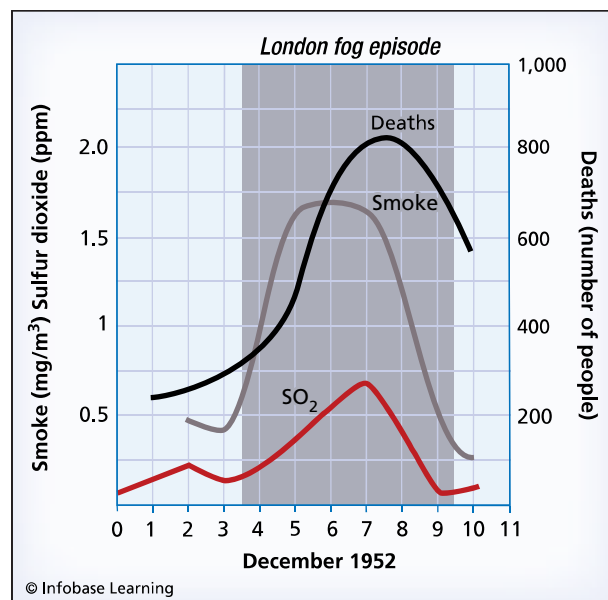
London is a big city, and many people die every day. Officials realized that there was a severe public health problem by the number of people swarming the hospitals, but it was not until the undertakers noticed that they were running out of coffins and the florists out of flowers that they realized the death rate had also increased. Only later was it determined that the number of deaths during the days of the smog was three or four times normal.

Health officials estimated that the smoke-laden fog was responsible for the premature death of about 4,000 people. A recent study estimated the longer-term death toll for the increased mortality rate through December 1952 at 12,000. For perspective, about 30,000 Londoners died in the Blitz during World War II. Most susceptible were those already suffering from chronic respiratory or cardiovascular illness, and they made up the majority of the deaths, but even some healthy people died. Some public health officials cautioned that the elevated death rate also could be blamed on an outbreak of influenza that occurred at about this same time.

During the disaster, average sulfur dioxide and TSP concentrations were estimated at 0.6 part per million (ppm) and 1,400 mcg/m<sup>3</sup>, respectively. The United States air quality standards limit sulfur dioxide levels to no greater than 0.03 ppm and TSP levels to less than 260 mcg/m<sup>3</sup>. Some estimates place the amount of pollution trapped in the inversion at 1,100 tons (1,000 metric tons) of smoke particles, 2,200 tons (2,000 metric tons) of carbon dioxide, 154 tons (140 metric tons) of hydrochloric acid, 15.4 tons (14 metric tons) of fluorine, and 407 tons (370 metric tons) of sulfur dioxide that were converted to 880 tons (800 metric tons) of sulfuric acid.

### THE AFTERMATH

Although this was not London's first "killer fog," as similar events had taken place in 1813, 1873, and 1891, the catastrophe in 1952 is widely regarded as spurring extensive epidemiological research into the



**Graph of smoke, atmospheric sulfur dioxide, and resultant deaths versus time during the London fog disaster in the early part of December 1952. The elevated death rate did not return to normal levels until January 1953.**

public health effects of air pollution. After an initial phase of skepticism, the British Parliament eventually became convinced by the mortality data and, in combination with strong constituent pressure, passed the 1956 Clean Air Act. This piece of legislation placed tighter controls on the release of air pollution and established stricter monitoring standards. In 1956, despite this new legislation, another killer fog struck the city, killing an estimated 1,000 people. Its causes were essentially the same, particulate and SO<sub>2</sub> trapped by a temperature inversion.

The 1956 Clean Air Act gave local governments the authority to provide funds to households to convert their coal-fired heaters for use of cleaner sources of energy such as gas, oil, smokeless coal, or electricity. Later, the 1968 Clean Air Act, which was aimed at industry and introduced the use of taller chimneys, was passed. Unfortunately, there was another smog incident in 1969.

Fortunately, today, in most developed countries, smog events such as the 1952 London Killer Fog are very rare. Changes in fuel types, more efficient furnaces, and the use of air pollution control devices have greatly reduced the amount of TSP released into the atmosphere. In the rapidly growing large and mid-size cities of India, China, and parts of Latin America, however, the potential still exists for a similar air pollution disaster. The use of coal, wood, diesel oil, and other forms of particulate-rich fuel combined with lax or unenforced air pollution control

regulations, in combination with just the right meteorological conditions, could result in a repeat of the 1952 London Killer Fog.

See also AIR POLLUTION; CARBON DIOXIDE; PARTICULATE; PRIMARY AIR POLLUTANTS; SULFUR DIOXIDE; TEMPERATURE INVERSION.

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#### Los Angeles air quality legislation Los Angeles, California 1943–present Air Pollution

One of the first names given to the area that would become Los Angeles by the 16th-century Spanish explorers was La Bahía de los Fumos, or “bay of smoke.” It seemed the smoke from their campfires tended to accumulate in the warm, still air of this portside on the west coast of the New World. By 1777, drawn to the area by the harbor and nearby freshwater rivers, Spanish missionaries established a small village and named it El Pueblo de Nuestra Señora la Reina de los Angeles del Rio de Porciuncula, roughly translated to the village of Our Lady, queen of angels on the Porciuncula River. Unlike on the East Coast of the United States, population growth was slow in the small village of Los Angeles, as it became known, with an estimated population in 1820 of only about 700 full-time residents. The situation changed in 1848, when gold was discovered in the foothills of the Sierra Nevada, some 400 miles (643.7 km) to the north. By 1850, California had declared itself to be a state and the population of Los Angeles had more than doubled to 1,600.

By 1876, Los Angeles was connected to the rest of the United States by the completion of the Southern Pacific transcontinental rail line, and, in 1892, a second “black gold” rush took place, when oil

was found in the plains south and southwest of the Santa Monica Mountains, Puente Hills, and Santa Ana Mountains, which surround most of modern-day Los Angeles and outline the 1,600-square-mile (4,144-km<sup>2</sup>) Los Angeles basin. With the oil, people and industry arrived, and by 1923, with 25 percent of the world’s oil produced within and around the city, the population had grown to almost 600,000, as one-third of all the people in California lived in Los Angeles. An unforeseen environmental benefit resulted from the oil discoveries, in that oil and associated natural gas quickly replaced coal as Los Angeles’s fuel of choice. As a result, the city inadvertently avoided an early air pollution crisis that certainly would have developed from the use of coal.

As the population grew, however, urban sprawl pushed people to outlying areas, away from manufacturing and business centers. To accommodate these population shifts, Los Angeles developed one of the most extensive urban mass transit systems in the United States. At its peak in the early 1940s, the Pacific Electric Railway operated more than 2,800 scheduled streetcars, along with high-speed interurban trains on more than 1,100 miles (1,770 km) of track. Many factors contributed to the demise of the Los Angeles rail system, including the widespread availability of affordable, mass-produced automobiles; inexpensive gasoline; and opening of the freeway system. Interurban rail service ended in 1961, and streetcars stopped running in 1963. It was another 30 years before the city had another rail-based mass transit system.

As the population of California increased from 7 million in 1940, to 15 million in 1960, and 30 million in 1990, there was a concurrent increase in the use of automobiles, buses, and trucks; generation of electricity; increased refinery production; and burning of fossil fuels. As more pollutants were put into the air, the factors that made Los Angeles such an attractive place to live—a flat-lying plain, a steady warm temperature (average 65°F [18°C]), a dry climate, surrounded by high sheltering mountain ranges, with mild winters, moderated by the nearby Pacific Ocean—became the main reasons why the air was becoming unbreathable.

#### CONTAMINATION OF THE AIR

In addition to helping to moderate Los Angeles’s weather, the mountain ranges surrounding the city also tended to trap air pollutants by restricting horizontal airflow and encouraging the formation of marine layer temperature inversions. This happens when cooling ocean water lowers the temperature of the air near the surface. Warmer, overlying air acts



Smog accumulating in the Los Angeles Basin begins to cover the city. (Jose Gil, 2008; used under license from Shutterstock, Inc.)

as a lid and prevents the cooler air below it from mixing or dispersing. This cool air creeps in over the city from the west and stays there, trapping pollutants and causing early morning to midday fog. This occurs most commonly in early spring through late summer.

By 1943, city residents began to notice, on a regular basis, that the cool morning fog stung their eyes and lungs. In 1944, the Los Angeles Bureau of Air Pollution Control was formed to “investigate the origin and causes of all known sources of air pollution.” Outlying suburbs and communities downwind of Los Angeles also formed similar air pollution control bureaus, boards, and departments. These early efforts by this patchwork assembly of politically weak and uncoordinated agencies to reduce emissions from the worst offenders, including railroads, lumber mills, and oil refineries, through education and voluntary cooperation were ineffective and, in summer 1946, Los Angeles and its nearby suburbs and unincorporated areas suffered through the worst air quality season ever, with visibility in downtown areas often reported as less than one mile (1.6 km) and thousands of people complaining about burning eyes and noses. This public outcry mobilized elected officials throughout the area, and, in October 1947, the Los Angeles County Air Pollution Control District (APCD) was formed to absorb and unify all other city and county air pollution programs.

### LEGISLATION TO REDUCE AIR POLLUTION

Focusing its early efforts on major smoke producers, by 1951, APCD had forced significant reductions in smoke emissions from iron foundries and open-hearth steel mills. The APCD also successfully mandated floating roofs for large oil and gasoline storage tanks to reduce the evaporation of hydrocarbons into the atmosphere. Without the large

amounts of coal that was being burned in other American metropolitan areas, and because of rigorous enforcement of antismoke laws, Los Angeles became one of the first “smoke-free” cities and started to be recognized as a national leader in air pollution control. As the 1950s progressed, APCD began to make efforts to control sulfur dioxide ( $\text{SO}_2$ ) emissions. The agency forced oil refineries to reduce  $\text{SO}_2$  emissions, successfully ended the open burning of garbage in landfills and, despite widespread public opposition, banned the use of residential garbage incinerators. This action ultimately cost the APCD director his job and raised the city’s waste disposal costs by \$20 million. By the middle of the 1950s, with all known major stationary industrial or commercial sources of air pollution within the Los Angeles basin eliminated or regulated, air quality should have improved, but it did not. Consequently, attention began to shift to the automobile, the one remaining source of air pollution that most scientists and engineers had dismissed long ago as a significant cause of smog.

Dr. Arie Haagen-Smit, working at California Institute of Technology, cobbled together equipment and, using techniques developed in the fragrances industry, successfully created a simulated gaseous atmosphere that had the look, smell, and physical effects of Los Angeles smog. He did this by exposing automobile exhaust to ultraviolet light in the presence of nitrogen dioxide, which was present as a result of low-temperature combustion of oil or natural gas. The chemical reaction created ozone and peroxyacetyl nitrate, the causative factors in the adverse health effects of Los Angeles’s photochemical smog. Neither the citizens of Los Angeles, who loved their cars and were not eager to accept any responsibility for fouling the air they breathed, nor the oil companies that made or sold the gasoline, nor the automobile companies that manufactured the



cars and buses were eager to embrace this new finding. Both industry and the public at large vigorously resisted changes in engine design, fuel composition, or driving habits. In 1954, Los Angeles reported 2.4 million motor vehicles, the highest number on the road of any city in the world. These cars, trucks, and buses consumed almost 5 million gallons (18.9 million L) of fuel every day. A 1966 study by APCD found that of the 16,000 tons (14,515 metric tons) of air pollutants emitted every day within the Los Angeles basin, 80–90 percent was from automobiles.

Armed with irrefutable scientific evidence, APCD initiated a three-phase attack on the problem of automobile exhaust. It began to fund technological studies to help develop better ways to control or reduce exhaust gases; it started a public education campaign providing methods to reduce air pollution and fuel consumption from automobile usage; and it requested that automobile makers consider engine modifications to reduce emissions. Years passed with no major breakthroughs, and, consequently, Los Angeles County sought to involve California state government in the problem.

In 1960, the California Motor Vehicle Pollution Control Act was passed. This bill mandated the first set of air pollution control standards for tailpipe emission in the country. It set a limit of 275 parts per million (ppm) total hydrocarbons and 0.5 percent by volume of carbon monoxide. The statewide Motor Vehicle Pollution Control Board had to certify any pollution control device claiming to meet this standard, and the law, cleverly written, created an instant mass market for the first such device that could be developed. At that time, one in every 10 cars built in the United States was sold in California. By August 1960, 100 companies, competing for an estimated \$700-million market, were frantically working on anti-smog pollution devices. In 1964, four devices developed by private companies were certified including three types of catalytic converters and one flame afterburner. This meant that one of these devices had to be installed on every new car sold in California after June 1965. In response, all of the major American automobile manufacturers, Ford, General Motors, and Chrysler, announced that they had developed their own emission control techniques. These devices included earlier versions of more modern systems that are standard equipment on new cars today such as balanced fuel and air injection systems, exhaust gas recirculation devices, catalytic converters, and positive crankcase ventilation devices. None of the private company devices certified in 1964 ever went into use. Later, the Motor Vehicle Pollution Control Board became the current California Air Resources Board, or CARB, which

has much broader powers to regulate stationary and nonstationary sources of air pollution.

In 1963, the federal government took a more active role in regulating the quality of air in the United States. Urged by Presidents Kennedy and Johnson, Congress passed the new Clean Air Act, which remained focused on research and funding, but not enforcement. By 1965, in the face of mounting public pressure as well as increased scientific evidence linking automobile exhaust to serious air pollution conditions, an amended Clean Air Act was passed. This amendment established vehicle exhaust emission limits modeled after those in California. The new law required emission control devices on all 1968 model cars sold in the United States. By then, however, air pollution control officials in California realized that the standards passed in 1960 were not stringent enough to address the Los Angeles smog issue. They wanted to pass even tougher air pollution control mandates than the federal legislation, a decision bitterly opposed by the automobile industry. They legitimately feared the technological and cost challenges associated with trying to meet 50 different emission standards in 50 different states. The final compromise reached with the proposed bill (the Air Quality Act of 1967) allowed the federal government to set emission standards everywhere in the country except California, a legislative condition that remains in effect to this day.

Not satisfied, California continued to lead the nation in air pollution control efforts. Its 1968 Pure Air Act proposed a set of far-reaching concepts that included requirements for state car fleets to use hybrid; steam; and natural gas-powered vehicles. California was also a key player in a 1969 federal lawsuit against the major American automakers for “conspiring to prevent, obstruct or delay the introduction of devices to control vehicular emissions from 1953 onward.” Reminiscent of the government’s massive legal battle with the tobacco industry and using data and information obtained primarily from California’s struggle to impose vehicle emission standards, the suit progressed slowly through the courts, hampered by lack of support from the Nixon administration. Not satisfied with its progress, Los Angeles County filed its own lawsuit in federal district court for \$100 million to recover costs associated with administering its antismog program and medical expenses for residents whose health had been impacted by air pollution.

Realizing that the California suit was probably the first of numerous similar state filings, as both New York and Illinois were considering actions, the automakers agreed to a deal with federal prosecutors. Although admitting no guilt, they agreed no

longer to conspire to obstruct development of emission control systems and to make royalty-free patent licenses available to any company wishing to develop or install these types of devices. This federal settlement, approved in late October 1969, resulted in the dismissal of all current and future state suits. In April 1972, the U.S. Supreme Court refused to hear a challenge initiated by 18 states seeking to overturn the ruling. The federal courts blocked similar lawsuits from proceeding in 1973.

Despite their losses in the courts, Los Angeles and California succeeded in raising the control of automobile exhaust emission to the level of a national policy issue. They also established a tradition of experimenting with far-reaching air pollution control measures, including pressing the federal government to require the use of unleaded fuels. A strange dichotomy has been occurring during Los Angeles's long fight to clean its air: The city continued to expand its highway system, dismantle its public transportation infrastructure, and encourage urban sprawl on a scale that essentially requires everyone to have a car and to drive it long distances. Despite this contradiction, since 1990, overall concentrations of metals, volatile organic compounds, ozone, sulfur dioxide, and particulates have steadily declined within the Los Angeles basin. Although still far from ideal, air quality generally has improved, despite the steady increased growth in population and private vehicle use. Clearly, the early aggressive efforts in air pollution control by Los Angeles County and California have led to a sustainable dynamic between economic growth and air quality. Whether that dynamic will continue to be successful into the future will depend, in large part, on the ongoing leadership and farsightedness of agencies such as the APCD and CARB.

See also AIR POLLUTION; CARBON DIOXIDE; OZONE; PARTICULATE; SULFUR DIOXIDE; TEMPERATURE INVERSION; VOLATILE ORGANIC COMPOUND.

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#### Louisiana-Pacific Corporation (LPC) *Kremmling and Olathe, Colorado 1983–1998*

**Air Pollution** There are few products that have changed building construction practices around the world as significantly as oriented strand board (OSB). First gaining widespread use in the late 1970s, OSB is a stronger, cheaper, and more versatile building sheathing material or structural panel than plywood. Manufactured from the renewable resource of specially cultivated, fast-growing, small-diameter trees, OSB was produced by the United States and Canada in 2001 in a total combined amount of more than 20 billion square feet (1.86 billion m<sup>2</sup>), and today its production rate far surpasses that of plywood.

This engineered "board" or panel is actually a series of layered mats consisting of thin, specially oriented or arranged wooden flakes or wafers sawed or chipped from logs and then mixed in a heated, pressurized process vessel with wood fibers and a waterproof exterior grade epoxy binder. The finished product is extruded as a large mat of predetermined thickness and cut to a standard size, usually four feet (1.22 m) wide by eight feet (2.44 m) long. Finished panels are used for exterior sheathing on residential houses and commercial structures and in other construction applications.

The manufacturing of OSB results in the generation of a variety of air pollutants including sawdust particulate from wood processing and handling, volatile organic compounds (VOCs) from thermosetting phenol-formaldehyde and isocyanate-based resins, and hydrocarbon emissions from fuels used to fire dryers and other process equipment. Modern OSB plants in the United States have been designed to comply with current air pollution control requirements, and most generally are operated in an environmentally conscientious and careful manner. The vast majority of plants use wood residue from processing operations as most of their fuel, although oil or natural gas also is used as fuel supplements or backups. As the manufacturing of OSB began to expand in the late 1970s through the 1980s, however, not all companies were as diligent as they should have been in ensuring that their operations were consistent with Clean Air Act regulations.

#### BACKGROUND

The largest manufacturer of OSB in the world is the Louisiana-Pacific Corporation, or LPC. Established in 1972, LPC was formed when its predecessor company (Georgia Pacific, or G-P) was found to

be “monopolistic in nature” by the Federal Trade Commission, which ordered G-P to divest itself of timber assets in the southern United States. By the early 1980s, LPC had grown to more than 13,000 employees working in more than 100 manufacturing facilities across the country. Today, after restructuring in the late 1990s, LPC has some 6,500 employees and \$2.6 billion in annual sales. It is no longer in the wood pulp industry and currently focuses its operations on producing, in addition to OSB, hardboard and other structural-type building materials utilizing engineered or composite wood products.

LPC was quick to recognize the value of the OSB market and aggressively sought to become the leading supplier in the United States. To that end, and with the help and encouragement of the state of Colorado’s economic development authority, in 1983, LPC began preparations to build two large OSB plants in Colorado, one in Olathe, about 300 miles (482.8 km) southwest of Denver, and another in Kremmling, about 100 miles (160.9 km) northwest of Denver.

When a company plans to construct a new plant or announces an expansion or major renovation to an existing facility, especially if that expansion or renovation results in increased production capability, one of the first things it must do is obtain new air pollution discharge permits. The applications, called Permits to Construct, must be approved by either the federal or the state environmental regulatory agency (in Colorado, the Air Pollution Control District [APCD]) before any groundbreaking or site preparation takes place. This ensures an adequate opportunity for public comment and gives the regulatory agency the chance to make certain that appropriate air pollution control devices are included in plant design. LPC followed the appropriate procedures and applied to the Colorado APCD for the necessary permits.

The permits were issued shortly before construction began and allowed the discharge of up to 78 tons (70.8 metric tons) per year of carbon monoxide and 102 tons (92.5 metric tons) per year of VOCs at Kremmling. Similar permits were issued by APCD for the Olathe plant, limiting carbon monoxide to 112 tons (101.6 metric tons) per year and VOCs to 116 tons (105.2 metric tons) per year. Emission limits were to be enforced by restricting the amount of product each plant could produce. The APCD determined a ratio of the number of tons of manufactured OSB produced to the number of tons of air pollutants emitted. A limit on production, enforceable by spot audits of manufacturing records, customer invoices, and other documents, limits the amount of air pollutants.

## POLLUTION AT THE FACILITIES

The Clean Air Act, which at that time was being administered in Colorado by the U.S. Environmental Protection Agency (EPA), not the APCD, established minimal air quality standards for each region of the United States. Incorporated into these standards is a program whose objective is the prevention of significant deterioration (PSD) of air quality. The special regulations contained within the PSD program are intended to provide extra protection to those areas where the air is already relatively clean. The PSD program requires industries seeking to increase the amount of pollutants released to the atmosphere in “attainment areas” to obtain special permits that limit the amounts of pollutants that can be discharged. It also mandates the installation of very stringent and expensive “best available control technology,” or BACT, air pollution equipment. PSD rules apply to major stationary sources with the potential to emit 250 tons (226.8 metric tons) per year of any air pollutant. LPC overlooked, did not consider, or perhaps intentionally ignored that the Olathe and Kremmling OSB plants were in designated attainment areas and required special air permits from the EPA before they could be built.

## LEGAL ACTION AGAINST LPC

One day in September 1983, an EPA inspector driving to another facility noticed smoke billowing out of a stack at the LPC Kremmling plant. Information gathered during his visit to the plant that day and on subsequent inspections led him to advise facility operators at both Kremmling and Olathe that the OSB plants were major stationary sources and required PSD permits. LPC did not agree, and thus began five years of legal and technical battles, eventually leading to a civil enforcement action and a trial in federal district court.

The EPA was seeking severe financial penalties against LPC for violating important provisions of the Clean Air Act by not obtaining PSD permits prior to construction of the Olathe and Kremmling plants. The EPA also asked for a court order barring LPC from any further Clean Air Act violations. As the defendant, LPC contended that it had obtained valid air permits from the APCD and that the control technologies already in use at both plants based on APCD requirements are the same ones that would have been required under a PSD permit. In addition, the plant had not violated any air quality standards, and, by the time the case had reached trial, LPC had already applied for PSD permits from the EPA.

In its 1988 decision, the court essentially agreed with LPC. The evidence and testimony presented

did not indicate that the company had gained any economic advantage or benefit by not applying for and obtaining the PSD permits prior to construction; nor was public health apparently impacted or threatened by plant operations prior to issuance of the permits. The presiding judge, however, was hesitant to let LPC escape without any penalty because, ultimately, it was LPC's responsibility to apply for and obtain all permits legally necessary to run its business. He assessed a modest \$65,000 fine against the company.

### OTHER VIOLATIONS

Although it is tempting to sympathize with LPC as the victim of overzealous and unreasonable government regulation, major issues related to the company's air emissions at Olathe and Kremmling started to surface during and shortly after the EPA's civil enforcement case.

In 1984, one of LPC's unions notified the APCD that the company had not included information on formaldehyde emissions from its press process lines. This required LPC to apply for new permits to cover these emissions, and these new permits reduced production to a maximum of 160 tons (145.2 metric tons) per day for both plants. In June 1985, APCD threatened to revoke LPC's air permits at both plants because of violations of smoke discharge limits. Because of the threatened revocations, LPC installed additional air pollution control equipment at both plants and APCD issued yet another set of permits.

Another permit revocation was threatened by APCD in early 1986, and LPC again made significant improvements to the Olathe and Kremmling air pollution control systems, which included further restrictions on OSB production of no more than 50,000 tons (45,454 metric tons) per year or about 140 tons (127 metric tons) per day at each facility. LPC promptly exceeded these production limits at both plants in 1986, manufacturing 105 million tons (92.3 million metric tons) at each plant and, in 1987, producing 124 million tons (112.5 million metric tons) at Olathe and 94 million tons (85.3 million metric tons) at Kremmling. Once these production quantities were reported, LPC prepared yet another set of permit applications and forwarded them to APCD, requesting permission to increase production limits at both plants to about 78,000 tons (70,760 metric tons) per year.

In that same year, four families living within one quarter-mile (0.4 km) of the Olathe plant fled their homes and filed suit against LPC for creating such noxious air pollution that they could no longer live

in the area. Witnesses testified during the trial that the plant increased production rates and associated air emissions at night, when state inspectors were less likely to be on duty and emissions were more difficult to see. The trial ended in 1993 with an award of \$2.3 million to the four families, with \$1.9 million of that amount included as punitive damages.

By 1990, LPC was back under the scrutiny of the EPA, with the agency's air pollution scientists investigating discrepancies between the amounts of air pollutants reported as emitted from the Kremmling plant and the amounts estimated from production volumes. The answer was simple: The facility was underreporting. On the basis of an investigation that started in Colorado, the EPA began to look at LPC facilities around the country. The company subsequently was charged with tampering with or disabling air pollution monitoring devices, filing false or inaccurate emission reports, and deliberately misleading federal air quality inspectors. In 1998, LPC pleaded guilty to these and other criminal violations and was fined \$37 million and sentenced to five years' probation. This was, at that time, the largest fine in Clean Air Act history.

The federal grand jury also charged the Olathe plant's superintendent and mill manager personally with Clean Air Act violations. Both individuals pleaded guilty, and the superintendent stated that the falsified pollution reports were prepared because of pressure from senior LPC managers to increase production volumes. The Kremmling plant closed in early 1992.

This conviction followed on the heels of a 1993 \$11-million settlement with USEPA for air pollution violations at numerous other LPC plants. As part of that settlement, LPC was required to install \$70 million worth of control equipment at various processing and manufacturing facilities in the northwestern and southern United States.

This was a turbulent time in the history of LPC, and the environmental problems the company was dealing with were symptomatic of a larger leadership gap and related dysfunctional business management culture. Eventually, the LPC chairman was replaced, and a new spirit of compliance and cooperation with environmental regulations and regulators took hold. Although LPC still struggles at times to fulfill its environmental commitments, the company's current success is not based on fouling the air of its neighbors or the communities in which it does business.

*See also* AIR POLLUTION; CARBON MONOXIDE; FORMALDEHYDE; PARTICULATE; VOLATILE ORGANIC COMPOUND.



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**Love Canal Niagara Falls, New York 1978**  
**Water Pollution** In the southeastern corner of Niagara Falls, New York (population 56,000), is a 36-square-block working-class neighborhood of neat, well-kept row homes, formerly part of a larger community known as Love Canal. Water plays a key role in defining the Love Canal as a neighborhood. Its northern and southern boundaries are demarcated, respectively, by Bergholtz Creek and the Niagara River, and the "center" of the neighborhood is now known as 99th Street, but it was at one time a dream turned nightmare.

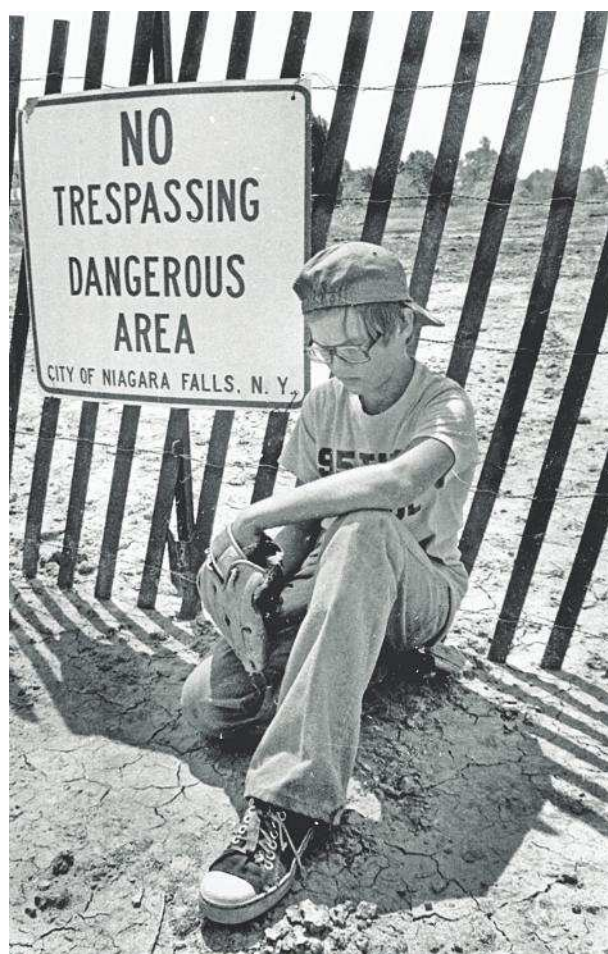
In the early 1890s, William T. Love, an enthusiastic and visionary industrialist, moved to Niagara Falls to build a canal connecting Lake Ontario and Lake Erie. He was convinced that not only would the canal provide a convenient shipping channel bypassing the rough waters of the Niagara River to serve the region's growing industrial base, but the flow of water through it could be harnessed to provide hydroelectric power. Love's vision was that the canal would be the center of a large industrial complex and city of more than 200,000 people, with electricity generated by the rushing water that dropped some 300 feet (91.4 m) between lake elevations.

The project was never completed, because of the economic panic of 1893 and the development of alternating current, which allowed electricity to be economically transmitted over long distances. The development company formed by Mr. Love went bankrupt, leaving a large hole in the ground 3,000

feet (914.4 m) long, 60 feet (18.3 m) wide, and 40 feet (12.2 m) deep. Love Canal, as the excavation became known, encompassed an area of about 16 acres (6.4 ha), eight miles (13 km) north of Niagara Falls.

### POLLUTION OF THE CANAL

The canal served as a local swimming hole for neighborhood children until the late 1930s, when it was purchased at auction by the Niagara Power and Development Corporation. This was during the Great Depression, and it was decided that the best use for the land was to restore it to productive use. To do so, it first had to be filled in to a usable level. The city of Niagara Falls and several other nearby communities began using the undeveloped area as the municipal dump. Not only was typical household refuse placed there, but Niagara Falls also allowed



Teenager relaxing in Niagara Falls on the fence surrounding Love Canal, Upstate New York, ca. 1978 (© Bettmann/CORBIS)

chemical wastes from its very active petrochemical industry to be dumped into the canal.

In 1942, a local manufacturer of industrial chemicals, fertilizers, and plastics started using the canal as a dump site. In 1946, Hooker Chemical, now Occidental Petroleum, purchased the property as a solution for its waste disposal needs. Between 1947 and 1952, Hooker Chemical dumped 43 million pounds (19,505 million kg) of industrial chemicals into the canal. Hooker also allowed the U.S. Army and several of its contractors to dispose of material from chemical warfare experiments. By 1952, the canal had been filled to capacity. After ending disposal activities, Hooker placed a state-of-the-art hard-packed, dense, clay/ceramic cover over the filled area to isolate the waste material and prevent infiltration by precipitation.

About 250 different chemicals were buried, mostly pesticides, but also other organic chemicals such as hexachloro-cyclohexane (HCH), chlorobenzenes, chlorinated hydrocarbons, benzene, chloroform, trichloroethylene (TCE), methylene chloride, benzene hexachloride, phosphorus, and polychlorinated biphenyls (PCBs). Most troubling were reports that approximately 130 pounds (59 kg) of toxic dioxin was buried in Love Canal. This 16-acre (6.4-ha) parcel, which was converted in the early 1950s into baseball and football fields, had become one of the largest repositories of hazardous wastes in the world.

### **PUBLIC EXPOSURE TO POLLUTION**

In the post-World War II years, the population of Niagara Falls, like that of the rest of the country, was growing quickly, and land for new schools and housing was desperately needed. The city approached Hooker and offered to buy the property it had used as a chemical waste dump to build a school on it. Hooker initially refused, but under threat of condemnation through eminent domain, sold the property to Niagara Falls for one dollar, the minimal amount for a contract to be legally binding. In the 1953 purchase agreement, Hooker disclosed what they had used the property for, warned about the potential dangers of developing the site, and absolved itself of any liability associated with future use of the property.

Within a few months of the sale, construction of the 99th Street School began. However, building plans had to be redrawn quickly when a contractor preparing the site found several pits filled with chemicals. The new location placed the school directly on top of the chemical landfill, and in order to dig the

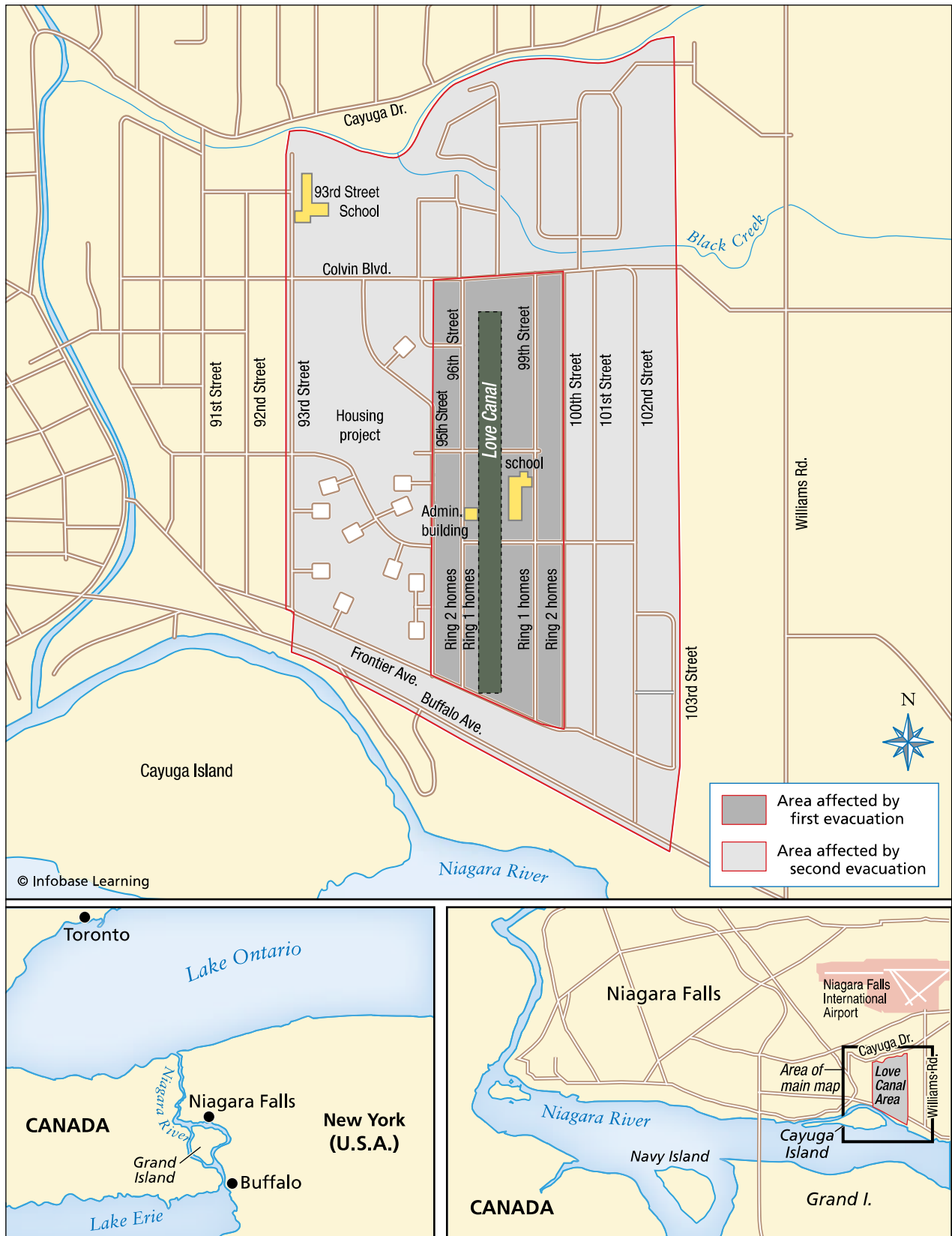
foundations, the tough clay cap Hooker installed to keep the waste isolated had to be removed.

By 1957, the Love Canal section of Niagara Falls was a neighborhood of about 200 houses, a large park, a winding creek, and a new 500-student elementary school. The city constructed sewers and installed water lines, further breaching the clay cover, for a mixture of low-income and single-family residences that were built on land abutting the disposal site. No disclosures were made to the families purchasing these homes about the potential risks associated with living so close to the chemical waste dump or even that the dump was there.

The geology of the Love Canal site played a major role in site development. Under a thin layer of topsoil ranging in thickness from a few inches to several feet is a layer of glacial till. This till is a mix of silt, sand, and gravel in a matrix of dense clay. Hooker recognized that one of the useful properties of this clay was that water did not move through it very quickly, if at all. The clay was relatively impermeable, making it ideal for waste disposal. Liquid chemicals and leachate from trash and other debris could be placed inside the hollowed-out partially completed canal, covered over, and would tend to remain in place. Although there were some natural variations in the till, sand lenses, and other higher-permeability zones, as long as water was prevented from having contact with and mobilizing the wastes, they would not present a significant migration pathway out of the disposal site. Underneath the till is sedimentary bedrock that is also fairly impermeable, further restricting migration. Love Canal was an appropriate waste disposal site, an impervious clay vault covered by a tight-fitting clay and ceramic lid.

As the lid or cover of the canal was breached, first by the school and later by sewer, gas, water, and other utility lines, water began to infiltrate the waste. Beginning in the 1960s, residents began noticing and complaining about strange odors in the area and about unusual substances that bubbled up in their yards and seeped through basement walls. The Love Canal vault was starting to fill with rainwater.

City officials investigated and attributed the odors to nearby chemical and industrial plants, but the problems only grew worse. Dogs and cats began to develop skin lesions. Children, after spending time in the school's ball field, started to have symptoms of skin irritation similar to poison ivy. Finally, in 1978, the "toxic time bomb" that Hooker had constructed and whose fuse was lit by the city of Niagara Falls, exploded. That year's record amounts of rainfall had filled the vault to capacity, and it began to overflow. Exploiting ancient drainage channels in the clay



(swales) that had been filled with more permeable sand and gravel, liquid wastes and contaminated groundwater began moving into the Love Canal neighborhood. On August 1, 1978, the *New York Times* front page story was about the chemical-laden leachate that had begun to drain onto the surface of the former dump site, entering streams, sump pumps, and low-lying areas throughout the residential community and onto the grounds of the 99th Street School.

Rotting drums containing pesticides “floated” to the surface in backyards and playgrounds, buoyed by a combination of frost heave and rising water table elevations. A swimming pool had been forced off its foundation from the hydrostatic pressure of the rising groundwater and was found to be floating on a layer of chemical waste. Foul-smelling puddles of unknown toxic substances appeared in ditches and other low-lying areas including the basements of some homes and on school grounds. Everywhere the air had the sickly sweet smell of solvents, and a number of children were treated for chemical burns on their hands and faces after playing outdoors.

### LEGISLATIVE REACTION

The city of Niagara Falls and state of New York were slow to react to the crisis. Since 1975, the Love Canal Homeowners Association had led an effort to investigate community concerns about the health of residents. They documented the high rates of cancer and birth defects occurring in the neighborhood. These efforts were aggressively opposed by both Occidental Petroleum, the successor company to Hooker Chemical, and many of their own elected officials, who still believed the chemicals were safely buried. It was not until a newspaper reporter from the local paper, *Niagara Gazette*, took samples from a sump pump in the affected area and demonstrated that the sludge contained the same chemicals Hooker had disposed of that governmental action began. Neither the school board, the city, nor Occidental Petroleum was willing to accept responsibility for the cleanup.

Faced with intense and growing media and public pressure, President Jimmy Carter declared a federal emergency at Love Canal on August 7, 1978, and approved emergency financial aid for the area. This was the first emergency funding ever authorized for anything other than a natural disaster. The U.S. Senate also issued a “sense of Congress” statement recommending that federal aid be allocated to address the serious environmental damage that had occurred. That same day, the New York gov-

ernor, Hugh Carey, told residents the state of New York would purchase the 200 homes most affected by the chemicals. By month’s end, 98 families had been evacuated, and 46 others had found temporary housing. Shortly thereafter, 221 families from the most contaminated areas left. The 99th Street School was closed and was eventually demolished.

Governmental officials again underestimated the extent of the problem. Neighbors of those whose homes had been purchased, some next door or across the street, were still concerned about their health and the health of their families. Property values had plummeted, and “buy one; get one” home sales were offered, with no takers. In May 1980, the U.S. Environmental Protection Agency (EPA) published the results of blood tests confirming that because of exposure to the toxic chemicals, Love Canal residents had suffered chromosome damage, greatly increasing their risk of developing cancer and having reproductive problems. Enraged by the findings and the government’s lack of action, residents forcibly held EPA officials hostage at a public meeting for two hours.

Confronted with escalating civil disobedience by respectable working-class people in conservative Upstate New York, President Carter agreed to evacuate all Love Canal families temporarily, pending appropriation of relocation funds. Eventually, almost 900 families were moved and their homes purchased.

### THE CLEANUP

The cleanup program was massive and incredibly expensive. None of the waste was removed: Safety analysis quickly demonstrated that the risks to workers and nearby residents from the excavation, packaging, and shipping of the mixed toxic waste were too great. Rather, a clay and synthetic cap was installed over the original 16-acre (6.4-ha) dump as well as another 40-acre (16-ha) contaminated area. A barrier drainage and leachate collection system was installed around the perimeter of the site to collect liquids that might leak out of the now-recapped fill area. Approximately 3 million gallons (11.4 million L) of contaminated groundwater and runoff is captured and treated every year before being discharged to the city’s sanitary sewer system.

Sewer and creek sediments that soaked up chemicals released from the dump were excavated and treated before being shipped to long-term disposal sites. The site is checked continuously for migration of hazardous chemicals through a system of groundwater monitoring wells. Current plans are to



maintain the cap, leachate collection and treatment systems, and monitoring program in perpetuity.

Occidental Petroleum settled some 1,300 homeowner lawsuits for \$20 million. Individual awards ranged from \$200,000 to \$1.4 million, depending upon how badly the family was affected. Occidental also reimbursed EPA for \$230 million in costs related to relocation of residents and remedial activities. The company also has assumed responsibility for the long-term operation and maintenance of the treatment system. The U.S. Department of Defense settled out for \$8 million, paid directly to EPA. The remainder of the cost, about \$160 million, was borne by the federal government and the state of New York.

### THE AFTERMATH

Residential areas southwest of the canal were demolished and are now separated from the rest of the city, along with the 70-acre (28-ha) recapped area, by an eight-foot- (2.5-m-) high, barbed-wire-topped, chain-link fence. It is unlikely anyone will ever live on the other side of that fence again. Parts of the community, however, have made something of a comeback. More than 260 homes previously evacuated west and north of the canal have been repaired and sold to new owners. Ten new apartment buildings have been constructed. Though access to the recapped area is still restricted, recreational buildings and facilities have appeared abutting the fence separating contaminated from clean. Finally, there are no more street signs pointing the way to Love Canal, and it cannot be found on maps; the area has been renamed Black Creek Village in a gesture to try to shake off the images associated with the actions of almost 30 years ago.

The events at Love Canal were directly responsible for the passage of CERCLA—the Comprehen-

sive Environmental Response, Compensation, and Liability Act, more commonly known as Superfund. This program, funded by a now expired tax on oil and chemical companies, provided the government the means to respond quickly and effectively to hazardous waste emergencies. It also held the polluter strictly liable for the environmental damage its wastes caused and allowed individuals to sue for personal and property damage resulting from improper disposal or spills of hazardous materials.

*See also* BENZENE; CHLORINATED SOLVENTS; CHLOROFORM; DIOXIN; GLACIAL DEPOSITS; HCH; LANDFILL; LEACHATE; METHYLENE CHLORIDE; PCBs; PESTICIDES; PHOSPHORUS; SUPERFUND SITES; TCE; WELLS.

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# M

**Magic Marker Site Trenton, New Jersey (1995–2001) Soil Pollution** In 1941, the Philco Company (later Ford Philco) purchased a 7.5-acre (3-ha) parcel of land in the heart of Trenton, New Jersey, one of the major industrial and manufacturing centers of the northeastern United States. Philco produced batteries for the military and needed a site with a skilled workforce that was close to the major transportation hubs of Philadelphia and New York. Trenton was the perfect location. At the time, the city of almost 125,000 was one of the country's leading manufacturers of steel, rubber, wire, rope, linoleum, and ceramics. The city's slogan, boldly emblazoned in huge letters across a bridge spanning the Delaware River and connecting New Jersey to Pennsylvania, stated, "Trenton Makes and the World Takes."

## BACKGROUND

Shortly after the end of World War II, the Gould Battery Company, a subsidiary of National Battery Company, purchased the property and began its own battery manufacturing operations. Gould manufactured two types of industrial and commercial batteries, starting batteries and deep-cycle batteries. Starting batteries are those that deliver a short, intense burst of electrical power needed to start engines, such as in automobiles and trucks. Deep-cycle batteries are designed to produce lower, steadier currents for electrically operated devices such as trolling motors on boats.

Both types of batteries are classified as lead-acid. Developed in the 1860s by a French physicist, lead-acid batteries are rechargeable and have a relatively high power-to-weight ratio; they deliver more elec-

tricity per unit weight than many other types of batteries made of different materials. This feature and their relatively low cost make lead-acid batteries ideal for use in cars, trucks, and even industrial equipment such as forklifts. The essential process of making a lead-acid battery has not changed much since the 1860s. A case (now plastic) is filled with a dilute solution of sulfuric acid and water. A series of specially perforated lead plates is placed inside this case. A mixture of lead oxide and powdered sulfates coats the plates, giving each plate either a positive or a negative charge.

The plates are arranged into groups (cells), with the positive and negative plates in each cell connected to positive and negative terminals on the outside of the plastic case. A typical car battery has six cells, which produce two volts per cell, for a total of 12 volts. An electrical current is generated by the chemical reaction that takes place between the positive and negative plates and is facilitated by the electrolytic (acid) solution. Electricity is produced if a complete circuit is formed between the positive and negative terminals, such as when a car's starter motor is engaged. Nearly 80 percent of the lead mined in the United States is consumed in the manufacture of lead-acid batteries. These batteries also have a very high recycling rate, primarily because of the credit given when a new battery is purchased and the old battery returned.

## POLLUTION OF THE SITE

As part of its manufacturer process, Gould decided to produce its own lead plates. This required the lead ore to be smelted to extract, or separate, the lead from other undesirable minerals or elements

present. Unless done under very controlled conditions, smelting, and particularly lead smelting, is notoriously damaging to the environment, producing large quantities of debris containing lead and heavy metals.

Gould also stored the sulfuric acid used to make the electrolytic solution in underground tanks on its Trenton site. Production operations gradually became more sophisticated until Gould was operating one of the most advanced commercial battery manufacturing plants on the East Coast. As process operations continued, however, the main building slowly started to decay, constantly under attack from the heat of the smelting operation and concentrated sulfuric acid being used to fill the finished batteries. Eventually, as Trenton began to lose its industrial base to other regions of the United States and foreign competitors along with many other northeastern manufacturing cities, Gould shut down its operations and donated the property to the county redevelopment agency.

After it had lain dormant for several years, in 1981, a Doral Industries subsidiary, Magic Marker Industries, purchased the site from the county agency. Doral refurbished the building and began production of pens, liquid crayons, and felt tip markers using such chemicals as propanol, butanol, and methanol. At peak production, Magic Marker had 200 employees. By 1989, Doral was in financial trouble, and its Magic Marker subsidiary filed for bankruptcy and abandoned the property.

During its operation, both as a battery manufacturer and as a writing implements company, neighbors complained about the often-overpowering chemical odors released by the plant. Given the dense population around the facility, which was directly across from an elementary school, local area residents became concerned that the abandoned building would become an eyesore and nuisance, attracting crime and posing a danger to children who might want to explore the building and grounds.

### THE INITIAL CLEANUP

It took several years, but by mid-1997, the Magic Marker Site, as the property came to be known, attracted the attention of the New Jersey Department of Environmental Protection (NJDEP). After several inspections, the NJDEP realized that they needed both financial and technical assistance to investigate the potential environmental impacts at the site. Acting at their request, the U.S. Environmental Protection Agency (EPA) identified some 200 drums and containers filled with acids, industrial solvents, and a wide variety of other chemicals. By

November 1997, the EPA and NJDEP initiated a joint \$450,000 removal program, financed largely under Superfund, that resulted in the safe sampling, repackaging, and off-site disposal of the abandoned chemicals. Part of this removal action included better fencing for the seven-plus-acre (2.8-ha) property, as well as sampling of adjoining sites to make sure contamination did not extend into the surrounding neighborhoods.

Once the immediate threat of a chemical catastrophe was abated, the question arose as to how to restore the property to productive use. Although the materials in containers had been disposed of properly, the upper 18 inches (45.7 cm) of soil across most of the Magic Marker Site was heavily contaminated with lead. In places, lead concentrations exceeded 1,000 parts per million (ppm). The NJDEP has established a safe level of lead in soil for residential uses of 400 ppm. With no one willing to buy and redevelop the site because of the widespread soil contamination, and with the risk to the public health and environment not serious enough to warrant the expenditure of additional Superfund monies, it seemed that the Magic Marker Site was destined to remain an abandoned, underutilized industrial facility for many years.

### BROWNFIELD CLEANUP

Brownfields are designated sites where historic industrial activity has resulted in a remedial or cleanup liability far in excess of the value of the property. These sites usually contain extensive or pervasive soil or groundwater contamination. Brownfields are most commonly associated with older urban areas where former industrial complexes once thrived that now lie fallow. Brownfield sites represent a blight on the community, a drain on the tax rolls, and a threat to the overall quality of life of nearby residents, who often are poor members of minority groups.

As the number of brownfield sites began to grow across the country, the EPA, New Jersey, and many other states responded with special brownfield development programs. These programs are designed to provide incentives for commercial builders to buy and redevelop the site, converting it into a benefit to the community. Incentives include protection from future liability or claims for damages as a result of the preexisting contamination, reductions in property taxes or awarding of tax credits, and, in some cases, federal or state grants that can be used to fund site remediation. In 2009, the EPA awarded more than \$160 million to communities in 44 states, two territories, and three tribal nations for use in property revitalization efforts.

To allow for redevelopment of the Magic Marker Site, in 1995, the EPA awarded a \$200,000 brown-field grant to the city of Trenton. The money was to be used for the demolition of the 175,000-square-foot (16,258-m<sup>2</sup>) manufacturing building and for field testing of an innovative remedial technology called phytoextraction. Phytoextraction uses the natural metal-absorbing capacity of plant roots, particularly of a certain type of Indian mustard plant (*Brassica juncea*), to remove physically or extract metallic contaminants that may be present within the root zone of the soil, generally the upper three feet (0.9 m). Working in cooperation with a private biotechnology company seeking to develop phytoextraction technology for commercial purposes, the city of Trenton began the cleanup program. The low cost and ease of application, as well as the nice look of the plant itself, made this remedial solution especially applicable for abandoned industrial sites in mixed-use or residential neighborhoods.

The soil at the Magic Marker Site is a mix of gravelly sand and industrial fill, including pieces of brick, slag, and cement. Two crops of the mustard plant and one crop of sunflowers were cultivated between 1997 and 1998. After harvesting, plant tissue samples were taken and assayed, or tested, for the amount of lead taken up by the plant. Soil samples also were collected as an additional check on the effectiveness of the phytoextraction process. To help make the lead more bioavailable, ethylenediaminetetraacetic acid (EDTA) and several other supplements were mixed into the soil before planting. Sampling results demonstrated that lead concentrations in the soil had been reduced by almost 60 percent in some parts of the study area. Mustard plant tissue samples contained up to 2,300 ppm lead, and sunflower stalks, roots, and leaves held up to 400 ppm.

Excavation and disposal of lead-impacted soil at the Magic Marker Site required the removal of 20,000 tons (18,144 metric tons) of material to ensure lead values met the 400-ppm residential cleanup criterion. The initial phytoextraction program produced only 500 tons (456 metric tons) of plant residues. It took an additional six to eight growing seasons, or about three years, before the lead contamination was reduced from an average of 1,000 ppm to the residential cleanup goal of 400 ppm. Other plants, such as corn and pumpkins, as well as the use of different soil amendments, are being evaluated to speed the removal of lead from the surface soils further. Eventually, the site will be used for a combination of public open space and residential development.

About 100 of these types of unused commercial and industrial sites are within Trenton, which lost

more than half of its manufacturing base between 1950 and 1990, as have many other cities throughout the United States. Similar sites in Trenton include a former brewery, auto salvage yard, and pottery manufacturer. The brownfields program at the federal level underwent a major expansion in 2006, when a change in the tax laws allowed environmental cleanup costs to be deducted in the year incurred, rather than capitalized over time. In addition, new legislation expanded the brownfields incentives to include deduction of expenses for the cleanup of petroleum products such as crude oil, crude oil condensates, and natural gasoline, which previously had been ineligible. Brownfield redevelopment programs, at both the federal and state levels, have played a major role in helping reclaim some of the most environmentally damaged property in and around the urban landscape.

See also BIOREMEDIATION; BROWNFIELDS; IN SITU GROUNDWATER REMEDIATION; LEAD; SUPERFUND SITES.

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**marine litter** The vast majority of ocean pollution does not occur as a result of the spectacular releases of oil from foundering tankers or oil well



blowouts, but as the quiet emptying of septic holding tanks from cruise ships at sea, the simple act of throwing bags of trash over the stern, and other seemingly innocent actions. This type of disposal, illegal under U.S. and most international maritime codes, is called marine litter and can be defined as any persistent discarded, human-produced solid material entering waterways, either directly by dumping or indirectly by being washed out to sea from rivers, streams, storm drains, and the like. Once discarded and in the ocean, most marine litter is very resistant to natural degradation, as shown in the following table.

Thousands of tons of marine litter are discarded into the ocean every year. This type of debris is a major problem along the world's shorelines and in coastal waters, estuaries, and oceans. Washed up on shore, marine litter poses both an aesthetic problem, detracting from enjoyment of the beach, as well as

a serious public health and ecological threat. It can kill or seriously injure many types of marine life and leads to disruptions in local ecosystems.

Approximately 25 percent of marine mammals, 15 percent of seabirds, and most of the world's oceangoing turtles have been affected to some extent by marine litter. One major problem is that of "ghost fishing" in which marine wildlife becomes entangled in discarded or lost fishnets. Other examples include plastic rings or bags that may ensnare marine life or fishing hooks and other debris that can be ingested by marine organisms.

Marine litter is found in all ocean and coastal settings including salt marshes, estuaries, and beaches. Isolation is no protection, as marine litter has been detected on the shores of Antarctica and floating in the Bering Sea. Its main component is plastic, which makes up about 60–80 percent of total marine

## Regulation of Ocean Pollution

People traveling in ships have routinely emptied sewage, trash, cooking water, oil, and other wastes into the ocean without regard to environmental impact. By the end of the 19th century, with its waterways and coastlines being heavily used, the United States began to recognize the need for control over this refuse. In 1899, the U.S. Congress passed the Refuse Act, which prohibited "throwing, discharging or depositing any refuse matter of any kind into the waters of the United States." The act was intended to reduce potential hazards to navigation, not to protect the environment. This was to be accomplished by reducing the amount of discarded floating wooden

crates and poles and sinkable metal and stone ballast debris. It focused on stopping the filling of channels by large amounts of trash, which required expensive dredging projects to keep the shipping lanes open. It was not until the early 1950s that a more unified and environmentally focused set of oceanic pollution-prevention regulations would be enacted.

In 1954, the United Kingdom organized a conference on pollution of the oceans by oil discharged from ships. This conference produced the International Convention for the Prevention of Pollution of the Sea by Oil. This was the first multinational treaty focused on protecting the environment. In it, the signatory

### MARPOL 73/78 DESCRIPTION OF ANNEXES

Annex	Topic	Effective Date
I	Oil	October 2, 1983
II	Noxious liquids carried in bulk	April 6, 1987
III	Harmful substances carried in packaged form	July 1, 1992
IV	Sewage from ships	United States not included
V	Garbage (trash) from ships	December 31, 1988
VI	Air emissions	Not yet in force

a. Annexes I and II are mandatory on all treaty signatories.

b. Annexes III, IV, and V are optional and not binding, unless the signatory country has specifically accepted them

debris. In more developed shorelines of heavily used waterways, such as the shipping lanes of the Atlantic Ocean, however, plastic waste can be as much as 90–95 percent of the total litter present.

Land-based sources are responsible for almost 80 percent of the volume of marine litter present in the oceans and in near-ocean habitats. This debris is transported by urban runoff through storm drains, from industrial and municipal discharges of untreated or only partially treated wastewater, and from the intentional or inadvertent disposal of trash into or near waterways. The second source of marine debris is that from oceangoing vessels such as commercial and recreational boaters, fishing crews, and offshore oil and gas exploration and production facilities. Solid wastes from these sources include wood, food wastes, glass, plastics, paper, cans, and cardboard. A typical cruise ship, for example, gener-

ates about eight tons (7.2 metric tons) of trash during each week of a voyage. Usually, this trash is burned, or incinerated, while the vessel is at sea, with the ash and residues unloaded at port or flushed into the ocean as sinkable waste. Sinkable wastes are those that have been processed in some way such as shredding or incineration so that they quickly fall to the ocean floor, thereby posing a less immediate risk to sea life and navigation.

For ships docking at most U.S. and European ports, it is illegal to dispose of solid waste within three miles (5 km) of shore, and for specific, sinkable types of waste, disposal needs to take place at distances ranging from three miles (5 km) to 25 miles (40 km) offshore. It also is illegal for vessels to dispose of solid plastics anywhere in the water. Ships are required to keep a log (the Garbage Record Book) describing the disposal and incineration of

countries agreed they would no longer allow oil to be discharged to the sea from ships. In 1958, the International Maritime Organization (IMO), an agency of the United Nations, was formed, and responsibility for management of the convention was transferred to that organization.

Later amended in 1962, 1969, and 1971, the convention was eventually transformed into the International Convention for the Prevention of Pollution from Ships (MARPOL, from “maritime pollution”), as modified in 1973 and 1978. MARPOL 73/78 expanded the regulation of ocean disposal of shipboard wastes from accidental and routine operations. It covers the release of chemicals and other liquids, hazardous plastic packaging materials, sewage, garbage, and air pollution via smokestack emissions. More than 160 countries as of December 2001 agreed to MARPOL 73/78. This convention is made up of 20 administrative or governing articles and five technical or regulatory annexes, as described in the table:

Although all the MARPOL 73/78 annexes have not yet been adapted by some countries, including the United States, the majority are currently enforced in ports, harbors, and shipping lanes around the world. In addition to MARPOL, there are many federal and state regulations that apply to ships operating in U.S. waters. The Clean Water Act, Port and Tanker Safety Act, and Oil Pollution Act of 1990 are, in many respects, more restrictive than MARPOL 73/78 regulations.

Both MARPOL 73/78 and other ocean pollution regulations contain exceptions related to ship safety. In the event of an emergency, the crew may take any

action it feels appropriate, including the discharge of oil or hazardous substances, to protect human life and the integrity of the vessel. Such releases can occur only after all other prudent efforts are made to correct the emergency, and they must be recorded in the ship’s log.

*See also* OCEAN DUMPING; OIL SPILLS; PLASTIC TRASH IN THE OCEANS.

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—by Robert P. Blauvelt

## MARINE LITTER DEGRADATION TIME

Description	Topic Degradation Time (at Sea)
Paper	2–4 weeks
Cotton cloth	1–5 months
Rope	3–14 months
Woolen cloth	1 year
Painted wood	13 years
Tin can	100 years
Aluminium can	200–500 years
Plastic bottle	450 years

Source: Hellenic Marine Environment Protection Association

solid waste at sea, and this log is subject to inspection and review by the U.S. Coast Guard and port authorities around the world.

See also CONTINENTAL SHELF; OIL SPILLS; PLASTIC TRASH IN THE OCEANS.

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**Marine Shale Processors Amelia, Louisiana (1985–1994) Air Pollution** In 1985, the Marine Shale Processors Company, or MSP, received permission from the state of Louisiana to receive and treat nonhazardous oil field waste (NOW) at their facility in Amelia, about 80 miles (129 km) south-

west of New Orleans. These residues, consisting of drill cuttings from oil exploration activities, oily debris, liquids, solids, and other materials that had had contact with or been contaminated by petroleum hydrocarbons, have a higher than average British Thermal Unit (BTU) value, and are, therefore, hazardous but also a source of energy.

MSP fed nonhazardous oil field waste into a rotary kiln, where it was heated to 1,600°F (871.1°C), and the oily constituents were evaporated or burned. The kiln was a 275-foot- (84-m-) long, slowly spinning horizontal cylindrical tube. The ash and other non-combusted residue from the kiln were further processed through one of two oxidizers, or afterburners, that operated at 2,300–2,700°F (1,260–1,482.2°C), and then it was sent to a "slag box" for cooling in a water bath. These solids were then chemically analyzed to ensure that no leachable metals were present. The hot gases also were fed through the oxidizers, passed through a wet quench system for cooling, and then mixed with powdered lime to neutralize any acid that might have formed. Finally, the exhaust gas was directed through a baghouse made of racks of cloth filters to remove suspended particulate matter before discharge into the atmosphere.

The solids quenching process generated a glass-like material that MSP called slagged aggregate. MSP planned to sell this now-inert vitrified slag as filler to be mixed with cement and asphalt used as a general-purpose backfill for road, dam, and other civil engineering projects. The oily debris and related material being treated were nonhazardous, and MSP was not required to obtain a permit from the U.S. Environmental Protection Agency (EPA) as a waste treatment facility. It was also not required to meet

the very stringent air and water pollution control standards associated with the incineration of hazardous chemicals.

### **POLLUTION OF THE SITE AND REGION**

Shortly after commencing operations, MSP began soliciting industries around the southeastern United States to use its facility as an inexpensive alternative for the disposal of hazardous waste. Prospective customers were informed that MSP was a recycling business that met the definition of an industrial furnace and, as such, was exempt from regulation as a hazardous waste incinerator under the Resource Conservation and Recovery Act (RCRA). This status gave MSP an enormous competitive advantage, which was reflected in very low processing costs, and consequently they received numerous waste management orders.

Suspicious of its claims that it was a legitimate recycler, the EPA evaluated MSP's operations against a set of criteria that it had developed to identify businesses that sought to bypass the expensive permitting and monitoring requirements associated with federal oversight of hazardous waste treatment, storage, and disposal by claiming to manufacture a product. The criteria were that hazardous waste could not be accepted in excess of the amount necessary to make the product, the wastes must be stored and handled in a manner consistent with their use as a raw material, wastes could not be solicited and accepted indiscriminantly, and records must be kept documenting recycling transactions.

On the basis of data provided by MSP and the EPA's own investigations, it turned out that MSP was accepting and burning large volumes of hazardous waste that had no apparent recycling value, including spent solvents and soil contaminated with heavy metals. MSP was also accepting and storing hazardous waste in volumes far in excess of those required to produce its aggregate product. In addition, MSP accepted all types of liquid and solid hazardous wastes, regardless of their composition or BTU value. These wastes were processed without regard to the effect they would have on the finished aggregate product. The EPA also found that the hazardous wastes being processed by MSP did not have any special properties needed to make the aggregate; rather, the wastes were simply being burned for the purpose of destruction. Finally, and perhaps most important, MSP was unable to demonstrate that any of its slagged aggregate had actually been sold for use as a product.

The Louisiana Department of Transportation and Development (LADOTD) had tested the aggregate

and found it unsuitable for use in cement or asphalt purchased for state projects. The wide variation in such physical properties as abrasion resistance and water absorption made the slag behave too unpredictably, and owners and operators of cement and asphalt mills were not allowed to add slagged aggregate to their products. Without LADOTD's approval, there was no market or end use for this material.

MSP used about 320,000 tons (290,299 metric tons) of its own slagged aggregate. It used about 147,000 tons (133,356 metric tons) of the material as general fill to increase the surface elevation of a portion of its property to above the 100-year floodplain. Another 174,000 tons (157,850 metric tons) was placed as general fill on a nearby 200-acre (81-ha) site owned by an MSP affiliate company that MSP's owners planned to develop into an industrial park.

### **RESULTING LEGAL ACTIONS**

The EPA, the Justice Department, and later the federal District Court did not find that this limited use of slagged aggregate qualified it as a legitimate recycled product. The facility was ordered either to apply for a RCRA permit as a hazardous waste incinerator or to cease acceptance of all hazardous materials. As the legal proceedings ensued, the EPA continued to inspect and assess MSP's waste processing operations. The facility eventually was fined more than \$6 million for discharging pollutants in violation of Clean Air Act and Clean Water Act requirements. Finally, in 1996, with its legal options exhausted, MSP ceased operations, fired the last 200 employees, and closed the facility. The enormous piles of aggregate that had accumulated on the site were moved to its adjacent property, Recycling Park, Inc., and spread and covered with a specially designed cap to help isolate it from the environment.

In 1994, the U.S. Department of Health and Human Services Agency for Toxic Substances and Disease Registry (ATSDR) conducted a public health survey of the area around MSP, including the small town of Amelia (population 1,800) and the much larger Morgan City (population 16,000). ATSDR was unable to determine whether operations at MSP represented a public health hazard because the data were not complete. ATSDR's study found, however, that the 1993–94 air and water emissions from the plant were not at levels representing a public health concern. On the other hand, data were not available from earlier operations, before the establishment of the facility's EPA-mandated air quality monitoring program. Similarly, ATSDR could not definitively link, excess rates of spina bifida and neuroblastoma



(a type of childhood nerve cancer) that occurred in St. Mary's Parish where MSP operations were located to MSP.

Unlike many spills or uncontrolled releases of hazardous wastes, MSP operations did not result in a catastrophic event with loss of life or obvious damage to the environment. Although the public health data are inconclusive, they seem to support a finding that, at least in the short term, no adverse affects were observed in the people living near the plant. The real value of MSP as a case study is that of what did not occur. As a result of the early, aggressive action by regulatory agencies, an environmental disaster may have been averted. Once under regulatory scrutiny, MSP may have exercised more care in its operations and processes than it otherwise would have.

*See also* AIR POLLUTANTS AND REGULATION; AIR POLLUTION; OFFSHORE OIL PRODUCTION; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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#### **Mason City Coal Gasification Plant Mason City, Iowa (1984–1990) Soil Pollution**

The turn of the 18th century marked the beginning of an energy revolution in the United States. Coal was cheap and plentiful and had a high British Thermal Unit (BTU) value that allowed it to provide heat for homes and power the blast furnaces and mills that produced the steel, iron, and finished goods

of the country's nascent heavy industrial sector. In contrast, coal was difficult to transport, and storage space, especially for large quantities, took up precious room in both homes and factories. It was dirty and left a black, carbonaceous residue on everything it touched. When coal burned, the smoke and ash produced were thick and a threat to public health. This was especially true in congested urban centers, where coal not only powered industry but also heated homes and cooked meals.

It had been known since the 1700s that if coal is heated (distilled) in the absence of oxygen, it forms coal gas, a highly flammable mixture composed primarily of hydrogen (50 percent), methane, carbon monoxide, and traces of other gases. Although coal gas had obvious benefits, it was not commercially available until 1805. In 1816, the city of Baltimore, Maryland, was awarded the first large contract in the United States to manufacture coal gas and install distribution piping so the city could use it for streetlights. A few years earlier, textile mills in Rhode Island and Massachusetts had begun lighting their facilities by using coal gas and, as a result, local coal gas companies were springing up all over the country, producing gas from plants primarily made from kits manufactured in New York City. By 1860, almost 300 manufactured gas companies were in operation and served approximately 5 million customers. Larger and more complex facilities were soon constructed to accommodate the ever-increasing demand for gas. As the smaller companies were eliminated from the market, eventually about 1,500 manufactured gas plants would dominate the supply industry. These plants heated coal and even oil to make gas using a variety of processes; two of the most common were the carbureted water gas and oil-gas methods.

The carbureted water gas process involved injecting a small amount of oil into a heated vessel of distilled, moist coal gas. The oil and moisture-rich coal gas combined, forming a fuel that had a high thermal (BTU) content. This enriched form, called blue gas, burned hotter and cleaner than other forms of coal gas, and this process soon was the process of choice for the manufactured gas industry in the United States. A carbureted water gas plant consisted of a brick-lined, cylindrical steel vessel called the generator, where the coal was cooked to produce the gas. From the generator, the gas went to the carburetor (carbureter), where it was physically mixed with oil. It then passed to a superheater, where the oil was thermally bonded, or "fixed," to the gas. Flowing beside a wash box, the moisture in the gas was allowed to condense and impurities settled out. The carbureted water gas would be passed through



Modern coal gasification plant in Beulah, North Dakota (David R. Frazier Photolibrary, Inc./Alamy)

a series of filters to remove remaining impurities before being discharged into a storage chamber that provided a continuous gas supply to the exhauster. The exhauster held the final gas-purifying equipment, and from there it flowed to the storage holder for eventual entry into the plant's distribution system and delivery to the customer.

The oil-gas process used liquid petroleum as its raw material instead of coal. First perfected in the late 1890s, the process was similar to the carbureted water gas method in that oil was steam heated in a generator vessel to release the gas. This gaseous mist then was sent to a vaporizer, where additional water was added before routing to the superheater. After leaving the superheater, the gas was purified and processed for distribution in a manner very similar to that for carbureted water gas.

The 1920s was the peak of manufactured, or "town," gas and manufactured gas plants (MGPs) in history. As manufactured gas had replaced coal, liquid oil and natural gas began slowly to supplant coal gas as the nation's energy source. At the end of World War II, manufactured gas was being phased out in favor of cheaper and cleaner-burning petroleum products, and, by the mid-1950s, MGPs had largely disappeared as part of the U.S. energy infrastructure.

### POLLUTION AT MGP PLANTS

As with any industrial process, MGPs produced residues and by-products, whether from simple coal gasification or the more complex carbureted water or oil-gas methods. These by-products were known as coal tars, and they were often left behind in soils and subsurface tanks and enclosures when the plants were closed. Coal tars and other MGP residues are toxic, and many are known or suspected carcinogens. These residues contain polycyclic aromatic hydrocarbons (PAHs) such as pyrene, phenanthrene, chrysene, anthracene, and benzo(a) pyrene, as well as benzene, creosote, cyanide, heavy metals, and phenolic compounds. Their presence in soil at former MGP sites can pose both significant public health and ecological risks. MGP residues can leach to contaminate groundwater or become airborne during site redevelopment activities. This causes particular problems, as many of the former MGP site operators simply went out of business and abandoned their plants with large amounts of wastes and residues remaining in the process vessels. Others were purchased by public utility companies, which demolished the surface facilities, redeveloped the land, and were unaware of the buried toxic residues left behind by former MGP operations.

### **Example of Mason City, Iowa**

One example of this type of problem is the Mason City Coal Gasification Plant Superfund Site, which is located on approximately 2.3 acres (0.9 ha) in a commercial and residential area of central Mason City. A north-central Iowa community of 29,000, Mason City is 220 miles (354 km) west of Sioux City. Between 1900 and 1951, an MGP plant operated to produce gas for lighting and heating. The plant was demolished in 1952 when natural gas service became available. Residues from coal gasification were buried on the site, along with some of the more heavily contaminated components of the plant. The land was acquired by Alliant Energy Corporation (formerly Interstate Power Company), which constructed a small electrical substation and storage shed on the property.

In 1984, Mason City negotiated an easement across the edge of the site to install a new sewer line. When excavation commenced, workers discovered an oily sludge, called coal tar, in subsurface soil at the site. Subsequent investigations by the site owner uncovered three underground storage tanks (USTs), also containing coal tars. The tanks and associated contaminated soil were excavated, but more contaminated soil was found in the north-central portion of the property.

The groundwater table is relatively shallow, only eight to 10 feet (2.4–3 m) below the surface, and the property's northern side is bounded by Willow Creek. This posed two environmental concerns: (1) that leachate from the site would discharge into Willow Creek and contaminate surface water and sediments, and (2) that coal tar residues would migrate downward and contaminate the underlying limestone aquifer (karst) that provides Mason City's drinking water. Eight Mason City municipal drinking water wells are within two miles (3.2 km) of the former MGP site.

### **THE CLEANUP**

To address soil contamination on the property, remedial actions included excavation of soil exceeding action levels. These action levels, based upon concentrations of certain PAHs present in the soil, were determined on the basis of the likelihood of contaminant exposure and the effects such exposure would have on sensitive people such as children, elderly adults, and infirm people. Once excavated, the contaminated soil and recovered wastes were sent to an off-site treatment facility for thermal desorption of adsorbed pollutants. More than 21,000 tons (19,051 metric tons) of material was processed by low-tem-

perature thermal desorption. After posttreatment sampling confirmed that these materials contained PAH concentrations below action levels, the soil was returned to the on-site excavation, compacted, and covered with a layer of topsoil and asphalt. This process eliminated the environmental and public health threat posed by the coal tar-contaminated materials.

During the soil removal action, however, several areas were identified where the levels of contamination exceeded the action levels but the soil could not be removed. These included soil near and underlying the power substation, beneath the sewer line that traversed the site, and beneath some subsurface concrete structures in the corner of the property. To ensure that these areas would not pose a future threat to groundwater, a long-term monitoring program was implemented and a contingency plan developed to control the migration of contaminants hydraulically, if they were found to be moving off-site or deeper into the water supply aquifer. A deed notice also was filed with the Mason City property tax and zoning offices that would alert future landowners to the presence of the treated and untreated soil and prevent the site from being used for residential or other sensitive purposes. The cost of the investigation and cleanup of this small site exceeded \$2 million.

### **A BIGGER PROBLEM**

The Mason City former MGP site situation is not unique and illustrates many of the problems that face former MGP property owners as well as the federal and state environmental agencies that regulate them. MPGs were widespread throughout the country, and, as the businesses failed, many of the sites simply were abandoned, demolished, or redeveloped and sold by their new owners, who did not realize the dangers that were buried beneath the ground. Over time, records that indicated the presence and operation of these facilities were lost, and many were only rediscovered by accident, as in the case of Mason City, or through a diligent search of historical land use maps or city directories. Many of the new property owners do not have the financial resources to address the cleanup of an MGP site, which can run into millions of dollars. Those former MGP properties owned by gas and electric utility companies, which were very active in the 1940s and 1950s in the purchase and phaseout or retooling of MGP operations, face extensive remedial obligations, often for more than one property. These obligations must be prioritized on the basis of the environmental and public health risks each site poses



and associated cleanup costs then passed along to the rate-payer.

*See also* AQUIFER; BENZENE; CYANIDE; INORGANIC POLLUTANTS; KARST; PAH; SOIL POLLUTION; UNDERGROUND STORAGE TANK.

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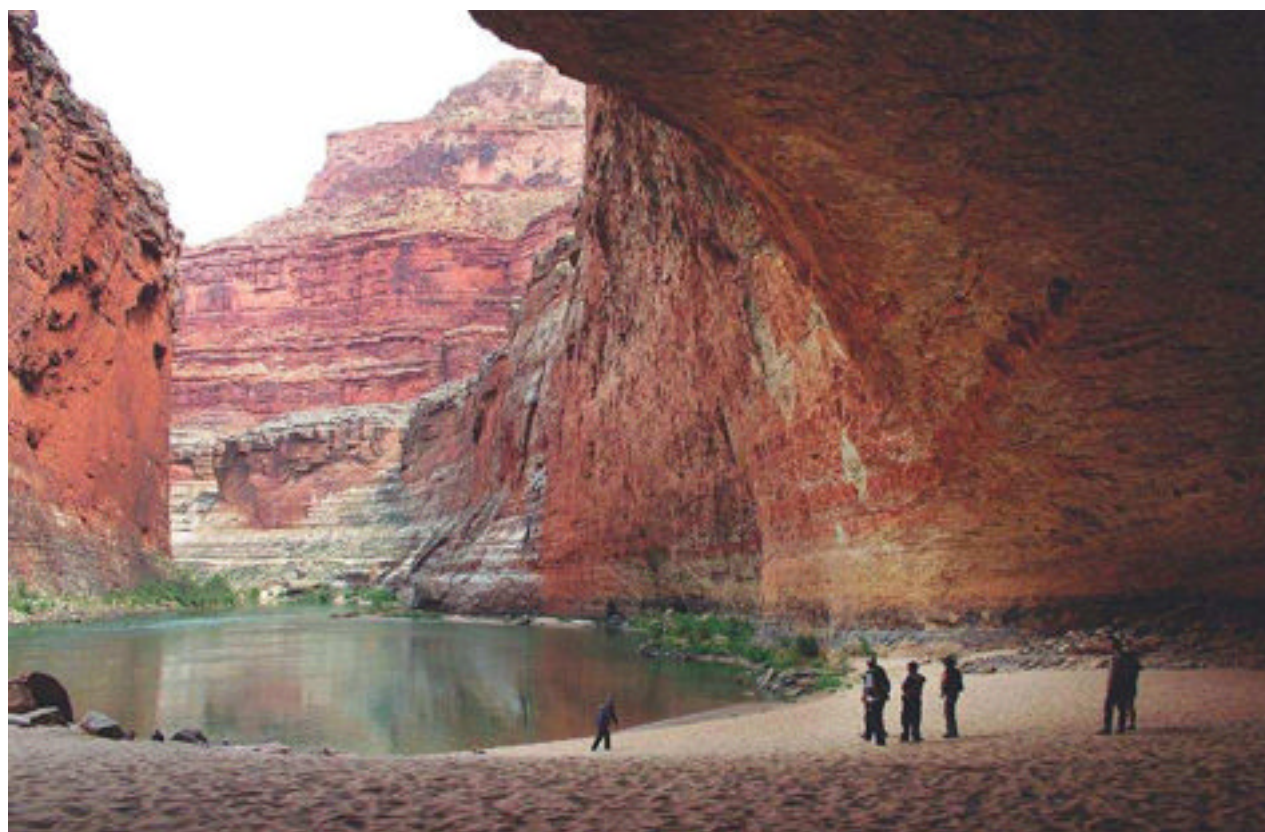
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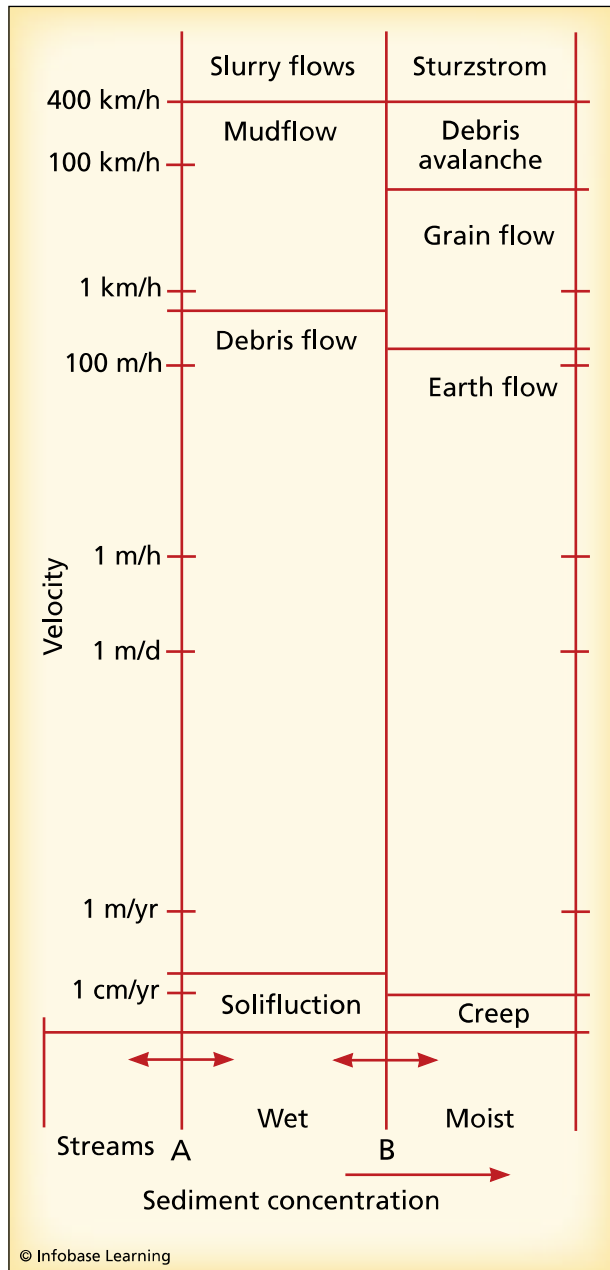
**mass wasting** Mass wasting is the movement of any material down a slope on the surface of the Earth. By definition, every slope is metastable, continuously seeking to flatten itself. The ultimate cause of mass wasting is the Earth's gravity. There are two vectors of force that are resolved from the gravitational force imposed on an object on a slope. One resolved vector is of normal force; it holds the object fixed on the slope; the other is a shear force, which drives the object down the slope. The combination of normal force and friction on the slope that acts against the shear force keeps the object in place. These forces combine to define a maximal slope angle that a material can retain, above which it fails. This is defined as the angle of repose, and it is unique for both the material and the conditions under which it exists. If the conditions change, then so does the angle of repose.

If sand is dumped onto a table, it makes a cone-shaped pile with the same slope angle on all sides. If more sand is added, the sand pile grows, but the slope angle remains the same. This is because the slope of the pile is at the angle of repose for



"Time and the river flowing . . ." is an example of how the Colorado River and mass wasting can form such magnificent landscapes as these massive exposures of the Red Wall limestone within the Grand Canyon. (AP Images)





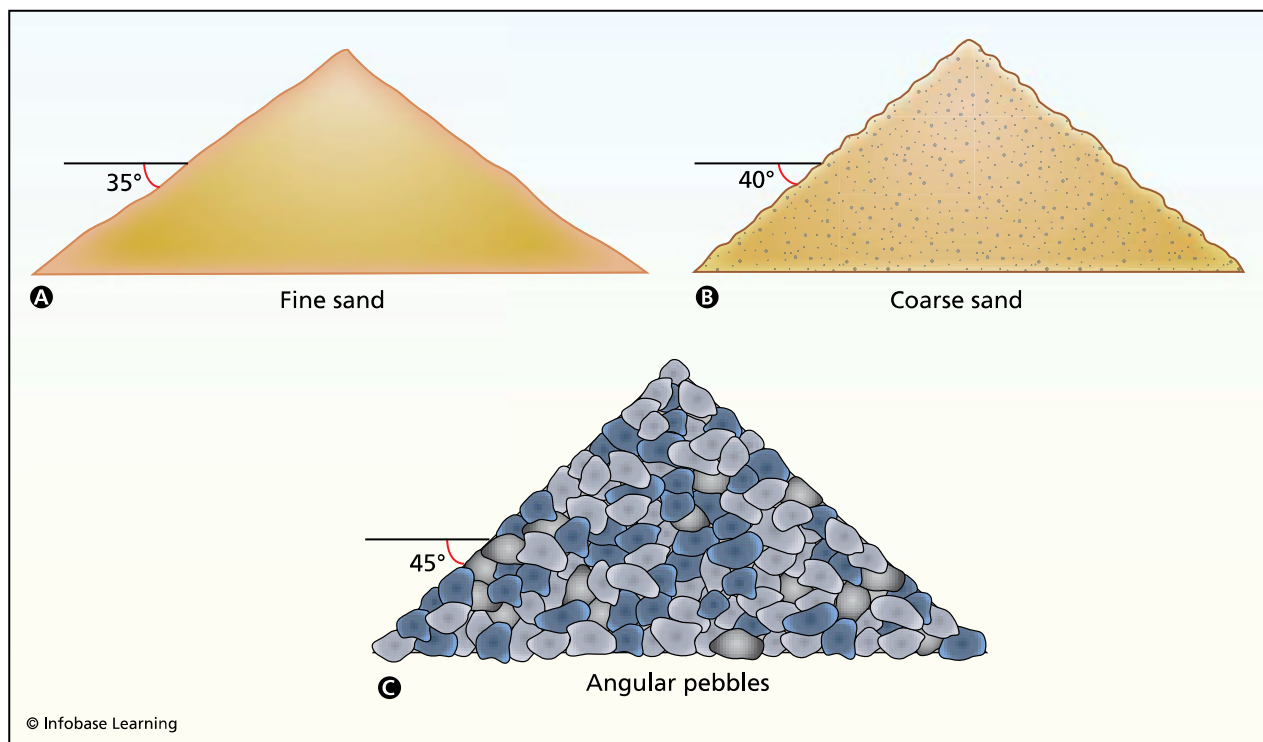
**Chart showing the various types of soil and debris mass movements and the velocity and water content of each**

those conditions. The slope does not keep the angle constant, if water is added to the sand, the angle of repose increases to near-vertical as the result of capillary action among the sand grains. This is why sand castles may be built at the beach. If water is added to the point of saturation, the sand flows, cannot maintain steep angles, and fails quickly. Ground shaking, as during an earthquake, reduces the angle of a slope, whereas planting trees, rerouting drainage, and building retaining walls all increase the angle of repose, the maximal stable slope.

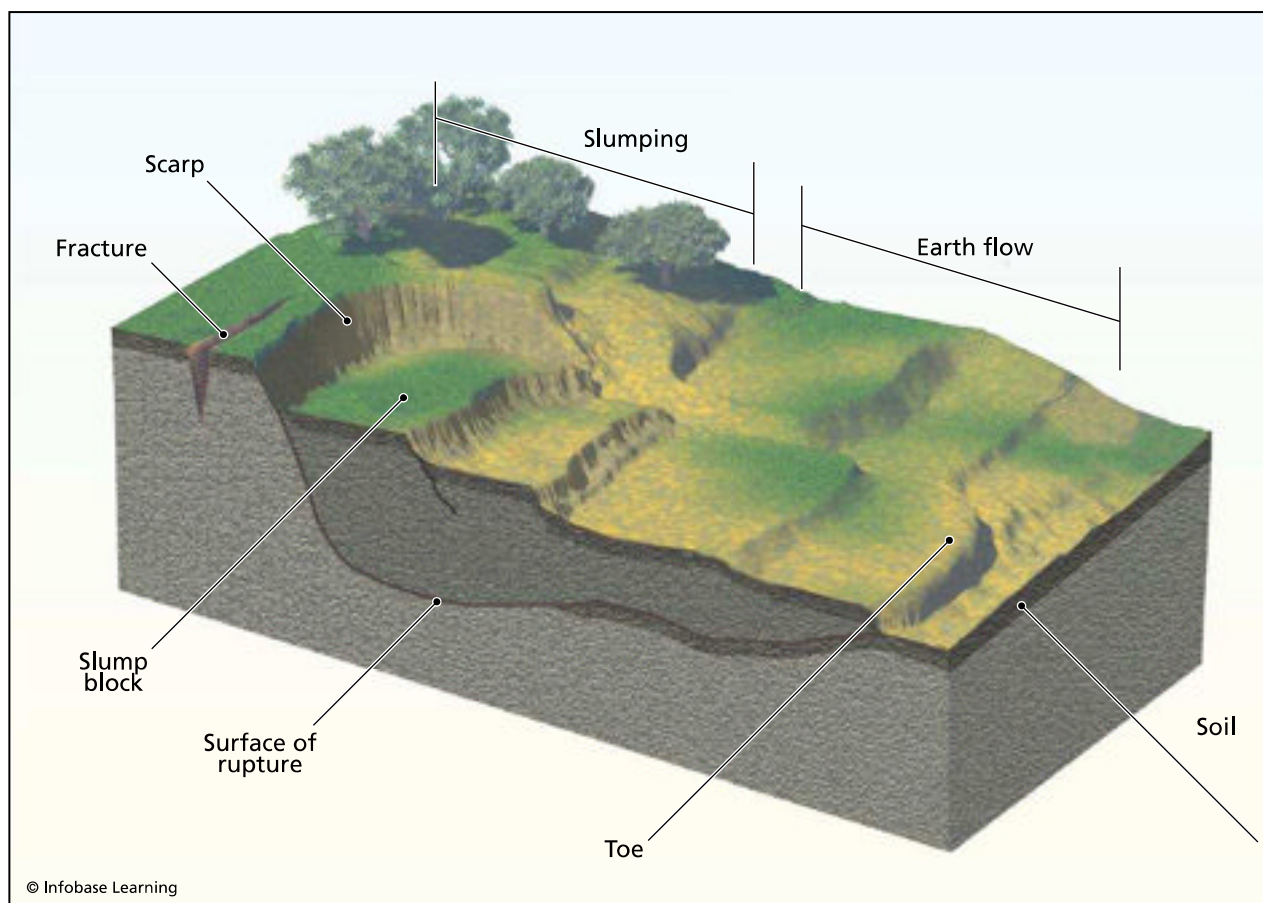
### CLASSIFICATION OF MASS MOVEMENTS

Mass movement of slopes can be classified by processes of failure and transport. The main subdivision for classification of mass movements is based upon material. Solid rock slope failures use a separate system from the movement of soil and surficial materials. The following is a list of the different types of mass movements:

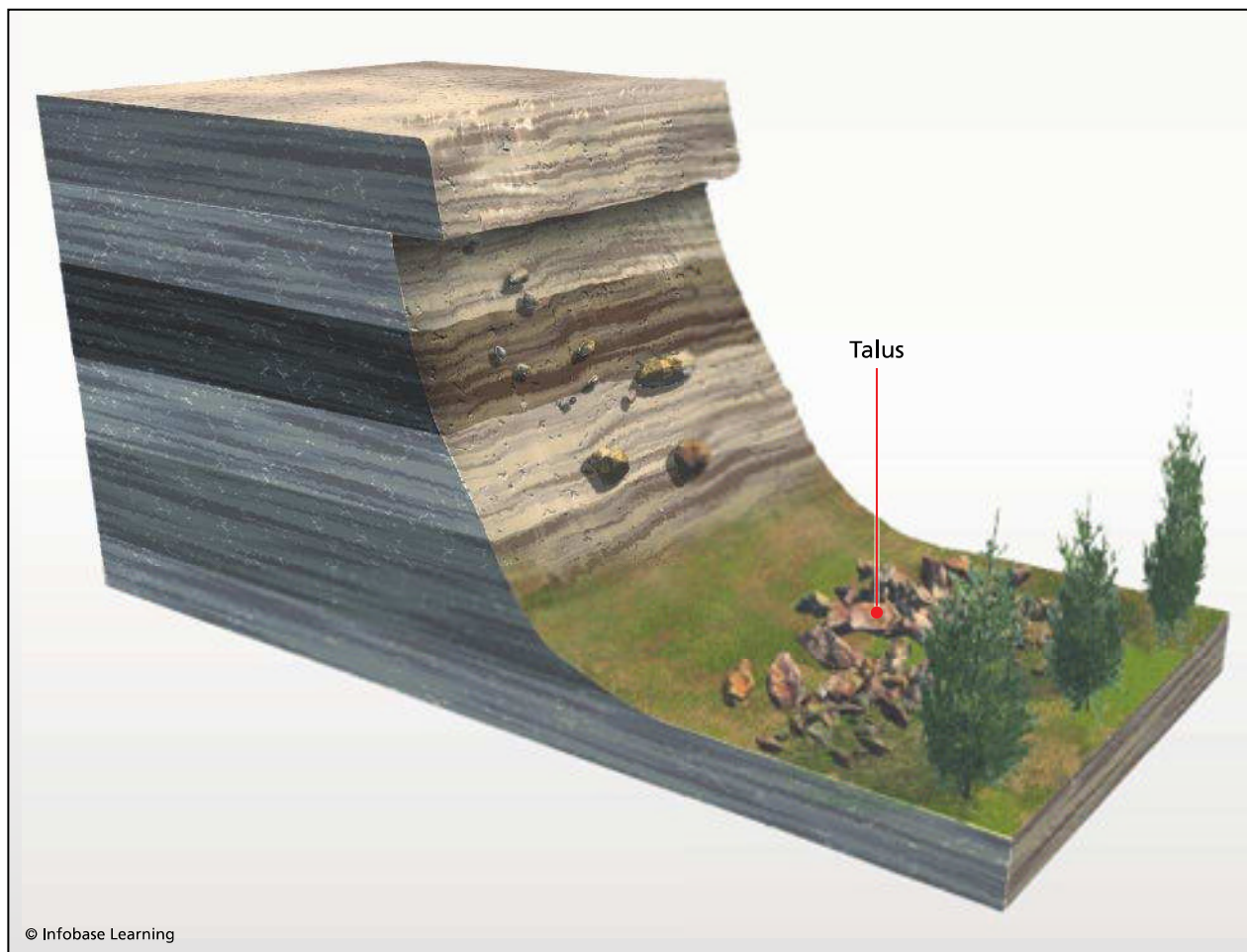
- *Rock failures* of faces on cliffs and slopes is based purely on the way the material falls. The release of the rock does not play a role in the classification but can result from an abrupt event such as an earthquake or a prolonged event such as the freezing and thawing of water in cracks (frost wedging).
- *Rock falls* involve the breaking away and free fall of rock from a cliff to the ground below. The movement is high speed and results in deposition of talus, or rock debris, at the base of the slope.
- *Rock slides* involve the breaking away of rock and sliding down a slope, usually along bedding or another surface that characterizes the rock unit. Rock slide also produces talus deposits. Other rock movements are variants of these two.
- *Rock topples* involve the breakage and rotation of a rock body into a free fall similar to a rock fall, for example.
- *Soil and debris failures.* The general term *landslide* captures many of the subdivisions of soil and debris slope failures. Basically, the amount of water in the material, the speed of movement, and whether the material is coherent or fragmented are the three factors in the classification of these failures. With less than 20 percent water, the fastest failure is a debris avalanche, which may begin as a rock or debris fall and gain speed. These mass movements contain rocks, trees, and other debris and travel at speeds of 60 miles (96 km) per hour to more than 250 miles (400 km) per hour. Grain flows are similar in composition but travel at slower speeds, between 60 miles (96 km) per hour and 325 feet (100 m) per hour. Earth flows are classic landslides with a coherent mass sliding down a slope at 325 feet (100 m) per hour to as slowly as 0.5 inch (1 cm) per year. Slower than this is the process of creep.



**Angle of repose for piles of several types of sediment: It is the maximal slope angle before the sediment slides down the hill.**



**Block diagram showing slumping, a type of landslide**



Block diagram showing a rockfall from a cliff with a talus slope or pile at the base

If the material in the mass movement contains between 20 and 40 percent water and the speed is 250 miles (400 km) per hour, it is called a slurry flow. Less than this speed but faster than 0.63 mile (1 km) per hour is a more common and generally more devastating mudflow. Debris flows are a bit more cohesive than mudflows but slower at 0.63 mile (1 km) per hour to 0.5 inch (1 cm) per year. They can also cause great damage. Solifluction is the slowest of the wet flows, at less than 0.5 inch (1 cm) per year.

### POLLUTION CAUSED BY MASS MOVEMENTS

There are a range of types of pollution caused by mass movements; they are largely pollution caused either directly by the slope failure or indirectly by things destroyed by the failure. Direct pollution is primarily the result of material moving into a stream, river, or other water body. The added material causes siltation of the river, which can be

muddy for days or even weeks after the failure. If such a failure affects a reservoir, it can render the water undrinkable for a time. These situations can occur with any type of mass movement. Significant amounts of particulate air pollution can be generated directly by an avalanche, typically in the form of powdered rock, or “rock flour.” Debris flows and mudflows expose soil to the elements. If the surface dries out and is swept into the air by wind, it can also generate pollutants.

Probably the main failure that causes direct pollution is from a mudflow. This sort of massive river of mud can flow down slopes and through towns, inundating everything. The forward force a thick flow generates can burst through the walls of any building and crush smaller and weaker buildings. They inundate the inside of the buildings after a collapse. Their great weight can cause sewers to back up and overflow; that overflow with the mud can infiltrate surface water supplies. In this way, the flow can promote disease. After the flow settles, the typically

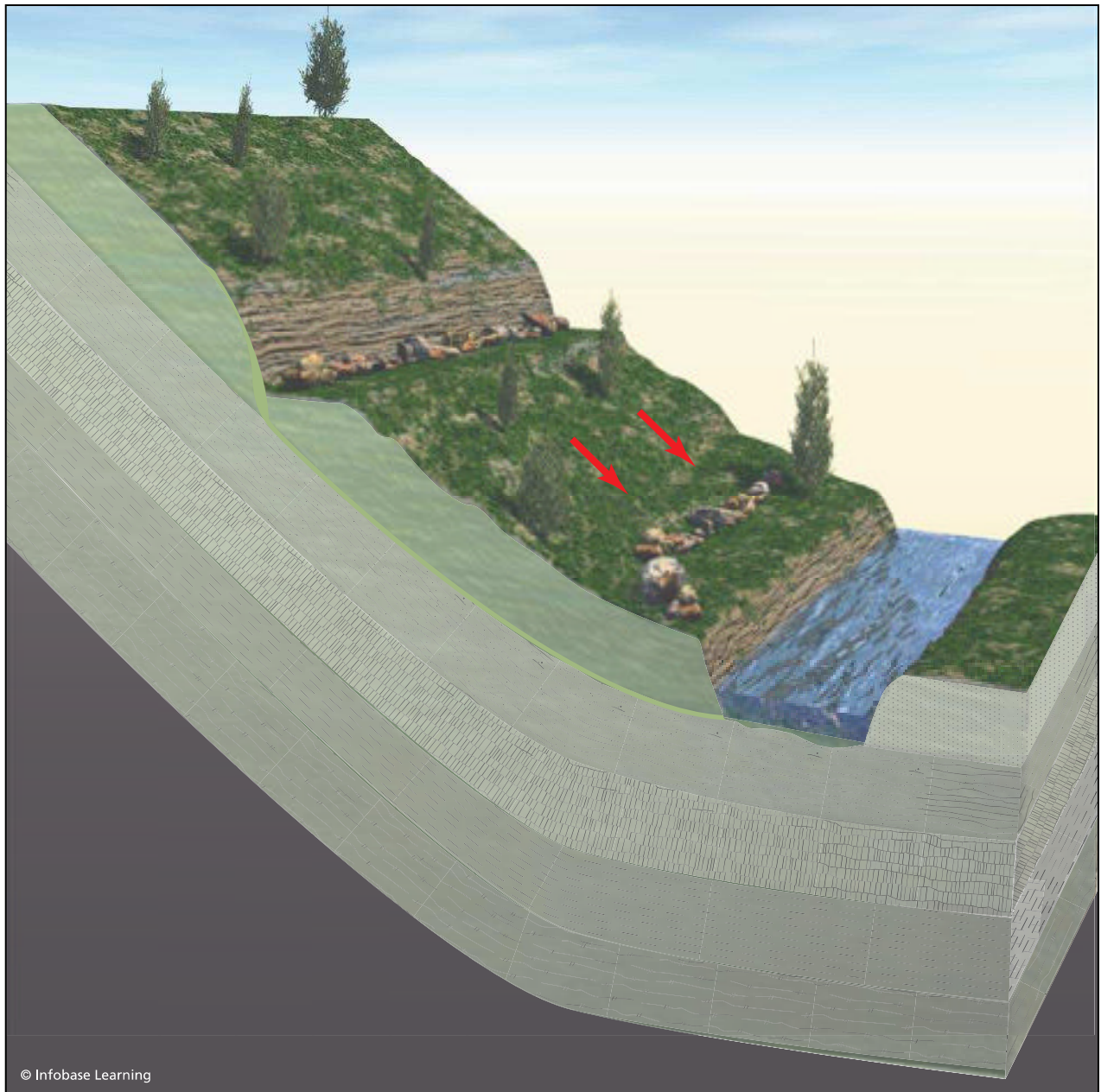


organic-rich mud can decay, adding to the cleanup, which can take weeks to months of full-time effort before it is complete.

Mass movements can destroy virtually any structure in a variety of ways. It is the job of civil and geotechnical engineers to anticipate these problems and plan accordingly. Their efforts can be observed on the slopes on the sides of highways nationwide. Any of the rock failures and high-speed slope failures can destroy structures as a function of the size of the failure and structure. These structures might be above-ground storage tanks, pipelines, rail lines with tanker

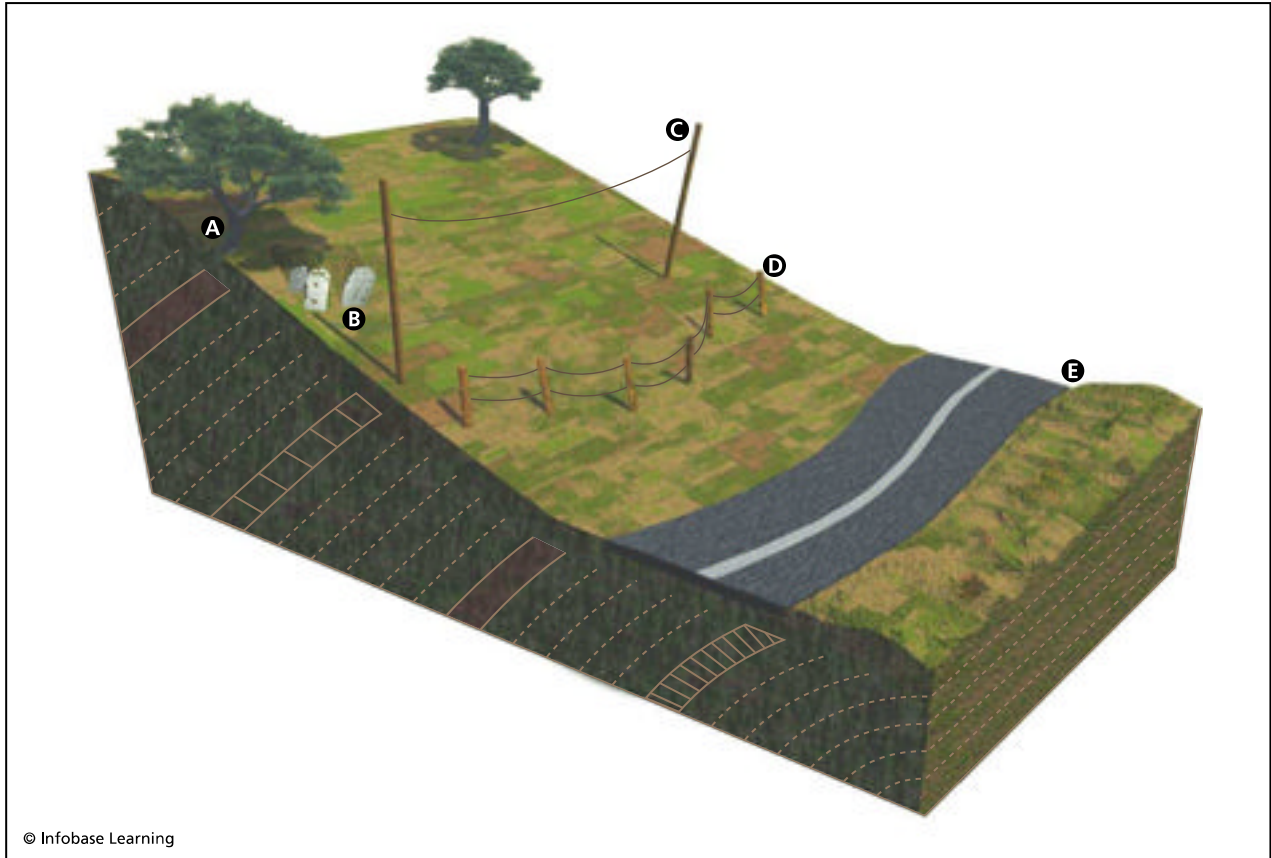
cars on them, manufacturing plants, and power generating plants. Spills of any number of chemicals are possible from such events, which aid in spreading the pollution with their continued movement.

Unlike many other natural disasters, slope failures may also rupture underground structures. They can unearth pipelines and underground storage tanks if they are on slopes that fail. If they are undermined, they can rupture or even slide down the slope, producing a chemical spill. Not only will the spill be spread by the mass movement; it can also flow down the slope. If a Superfund site sits on a hillslope, it



**Block diagram of inclined layers of rock and a rockslide or debris slide along them**





**Block diagram showing creep mass movement and some results of features on the slope such as a J-shaped tree (A), fallen gravestone (B), tilted utility pole (C), drifted fence line (D), shifted road (E)**

too may be disrupted by a mass movement, causing a potentially even more dangerous situation. If gas lines are ruptured, a gas leak can cause local air pollution and a significant risk for explosion. In earthquakes, one of the main causes of hazardous chemical spills is mass movement.

Another, less common result of a mass movement is from a tsunami. In 1957, an earthquake shook loose an avalanche in Lituya Bay, Alaska. The avalanche hit the water in the bay with such force that it generated a wave that climbed 1,700 feet (523 m) up the facing side of the bay, stripping it of trees, other plants, and soil. This is the largest wave ever recorded. There is good documentation of other tsunami waves that were generated by underwater landslides, notably in the Philippines and eastern Canada. A similar situation occurred in a reservoir behind the Vaiont Dam on the Pieve River, Italy, in 1963. A rock slide into the reservoir occurred after a particularly heavy rainstorm. The volume of rock displaced so much water that the reservoir level topped the dam and generated a 650-foot- (200-m-) high wave that devastated the valley, killing some 3,000 people. These occurrences add all of the

environmental hazards of a tsunami strike to those generated by the mass movement, causing even more damage.

*See also* EARTHQUAKES; STREAMS; SUPERFUND SITES; UNDERGROUND STORAGE TANK.

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**MBK (methyl butyl ketone)** Commonly known as 2-hexanone and propyl acetone, MBK is an odd pollutant in that it was formerly produced for use in commercial products. It was found, however, that the adverse health effects on the workers and threats to public health far outweighed the benefits, and its use slowly waned to the point that it is no longer produced or even used much in the United States. This should have eliminated MBK from concern, but that is not the case. MBK is also an unwanted waste product of many industrial processes including wood pulp production, coal gasification, and oil shale processing. It is, therefore, quite plentiful in certain areas. MBK has been ranked as the number 72 worst environmental threat of the 275 chemicals on the 2007 CERCLA Priority List of Hazardous Substances, and it has been found in 199 of the first 1,416 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where it was tested. Considering the limited availability of MBK, this is a very high ranking, reflecting the danger posed by the adverse health effects.

### PROPERTIES, USE, AND PRODUCTION

MBK is primarily a synthetically produced organic hydrocarbon solvent, but very small amounts also occur naturally in some foods such as cheese, nectarines, nuts, bread, milk, cream, and chicken, among others. In its pure form, it is a clear, colorless liquid with a sharp acetone-like smell. MBK was commonly used as a solvent in several applications, including paints, lacquers, ink thinners, nitrocellulose, glues, resins, oils, fats, and waxes, and in printing of plasticized fabric. It was also used as an evaporating solvent for nitrocellulose acrylates, vinyl, and alkyd coatings. One source claimed that domestic production of MBK was less than 1,000 pounds (454 kg) by 1975, but it could not be verified.

### ENVIRONMENTAL RELEASE AND FATE

MBK is primarily a point source pollutant from current wood pulp, coal gasification, and oil shale operations and from leakage from older toxic waste sites. MBK evaporates readily, so release to the atmosphere, either directly or indirectly, is significant. Once in the air, MBK is degraded quickly with a removal half-life of about two to three days by reaction with photochemically produced hydroxyl radicals. Minor amounts may also be returned to the Earth in precipitation as washout. If it is released into the soil, a significant amount evaporates from the surface in both wet and dry conditions. That which penetrates the surface is mainly broken down by soil microbes.

Experimental tests indicate that up to 60 percent of MBK may be removed in five days by biological action under certain conditions. Normally, the process is slower. MBK is relatively mobile under most soil conditions and may be leached into the groundwater system, where it may persist for longer periods. MBK has been found in groundwater systems near waste sites and oil shale or coal gasification facilities in Florida, New Jersey, Delaware, Michigan, Wyoming, New York, Quebec, and West Virginia, among other locations. If it is released into surface waters, evaporation is, again, the primary mode of removal. Experimental studies indicate that the removal half-life by vaporization is seven hours for a river and 164 hours for a lake, depending upon conditions. Some studies claim that it can persist for 10–15 days in rivers. MBK has been detected in Lake Erie, among other surface water bodies. That which is not evaporated may adsorb to certain particles in the water and settle into the sediment, where it may persist for long periods depending upon bacterial action. MBK will not bioconcentrate in plants or organisms.

### HEALTH EFFECTS FROM EXPOSURE

Exposure to MBK has been found to cause several adverse health effects. Acute exposure to its vapors at moderate levels produces transient eye and nasal irritation. Some eye damage from it can be permanent. Continued exposure to it produces central nervous system effects, including fatigue and sleepiness, followed by weakness, loss of coordination, and numbness and tingling in the hands and feet. Long-term chronic exposure to it may result in inability to walk, minor paralysis, reduced immune function, and possible long-term to permanent neurological damage. Pregnant animals that were exposed to MBK were found to have fewer surviving offspring and lower birth weights.

### REGULATIONS ON HUMAN EXPOSURE

MBK is regulated only by federal agencies that are concerned with the health and safety of workers. The Occupational Safety and Health Administration (OSHA) set a limit of five parts per million (ppm) of MBK in workplace air (PEL) during an eight-hour workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set a more stringent limit (REL) of 1 ppm for a 10-hour day, 40-hour workweek and immediately dangerous to life and health (IDLH) concentration at 1,600 ppm. The NIOSH National Occupational Exposure Survey of 1981–83 estimated that 1,778 workers were exposed to MBK in the United States.

See also ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; ORGANIC POLLUTANTS; SUPERFUND SITES.

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**McKin Disposal Company Gray, Maine (1972–1985) Water Pollution** Although known primarily for its picturesque shorelines, forests, and rustic lifestyle, the state of Maine plays an important role in the trade, service, and finance sectors of the U.S. economy. Maine is a major producer of paper and wood products and is an important center in the manufacture of transportation equipment. Industrial minerals such as granite, sand and gravel, zinc, and peat also contribute to the state's economic output. Bath Iron Works, one of the largest builders of complex, technologically advanced naval ships in the country, is Maine's largest employer. Many of the raw materials and fuel for these and other commercial activities that take place throughout Maine enter the state through Casco Bay.

Portland, the largest city in Maine, lies on the southwest coast of Casco Bay. The bay is a commercial shipping channel, tourist attraction, and fishery. Timber, minerals, and finished goods pass through Casco Bay to and from Canada and the lower East Coast and to the port of Portland for off-loading and transshipment westward. The bay and its associated 1,000 miles (1,609 km) of adjacent watershed include 25 percent of Maine's population and host annual commercial and industrial businesses, fisheries, shellfish, and recreation/tourism activities worth almost \$500 million.

Like other working ports, Casco Bay is struggling to maintain its environmental quality. Most recently,

it has been seeking to balance the impacts of nearby growing population and regional economic expansion with negative impacts to surface water and air quality. Forty years ago, however, a more fundamental assault on the bay occurred; it helped shape how environmental cleanups would take place across the United States.

#### THE OIL SPILL

In the early morning of July 22, 1972, the Norwegian tanker M/V *Tamano*, chartered to Texaco Inc. and loaded to capacity with no. 6 fuel oil (also called Bunker C), was making its way slowly and carefully through Casco Bay toward Portland. Onboard were an experienced crew and a licensed harbor pilot; the weather was clear and the channel well marked. It was for this reason that it was a complete surprise when the ship struck a submerged outcrop of granite called Soldier Ledge. The collision tore a hole in the hull and 100,000 gallons (378,541 L) of heavy industrial fuel oil promptly spilled into the waters of Casco Bay. One of the major causes of the grounding was eventually linked to a buoy that had been moved or had drifted and falsely marked Soldier Ledge as part of the shipping channel. Cleanup operations including off-loading of oil that remained in the tanker were delayed for several hours as industry and government officials argued over who was responsible and who would be in charge.

Bunker C is a fuel oil used to fire large industrial boilers. It is viscous and produced by blending heavy petroleum residues with lighter oils. Once spilled, Bunker C is very persistent, with only 5–10 percent expected to evaporate within the first few hours of entering the water. It tends to break up into discrete patches called tar balls, rather than forming extensive slicks. These tar balls can be a few inches to several tens of feet in diameter and can be carried hundreds of miles from the spill site by currents or winds. Fortunately, because of their density, once these tar balls make landfall, they tend to stay on the surface of the beach and are relatively easy to identify and scoop up. In the case of the Casco Bay spill, the cleanup took several months and cost millions of dollars, most of which was paid by the *Tamano*'s insurers.

The wreck of the *Tamano* did not result in far-reaching or long-lasting environmental consequences. The spill was addressed, and, fortunately, ecological damage to beaches and wildlife was kept to a minimum. The real impact to Maine's environment did not result from the *Tamano* spill but from its cleanup. More specifically, the coagulated Bunker C was skimmed from Casco Bay and scraped off its beaches properly; the problem occurred when it was sent to the McKin Company disposal facility.

## BACKGROUND

About 30 miles (48.3 km) north of the *Tamano* spill and 15 miles (24.1 km) north of Portland, a seven-acre (2.8-ha) sand and gravel pit was located just outside the small Maine town of Gray. For many years, the sand, gravel, silt, and clay had been excavated for use as local building materials, primarily by cement and construction companies. The pit varied in depth, between 6 and 20 feet (1.8–6.1 m) deep. When the sand and gravel were exhausted, the McKin Company purchased the site. Starting in 1964, McKin began operations as a tank cleaning and waste removal company. McKin sent tanker trucks and service crews to industrial facilities throughout New England to clean out chemicals and process tanks and take the wastes back to their Gray facility for processing. The property was used for the collection, storage, disposal, and transfer of petroleum and industrial chemical waste.

The facility underwent a major expansion in 1972 in order to handle wastes from the *Tamano* spill. An incinerator was installed to burn Bunker C contaminated soil and cleanup residues. This incinerator was supported by other waste management facilities, including an asphalt-lined treatment lagoon, 22 aboveground storage tanks, and storage pads for drummed wastes. Between 1972 and 1977, McKin processed between 100,000 and 200,000 gallons (378,541–757,082 L) of liquid waste per year, making it the largest waste processing facility in New England and one of the largest in the eastern United States.

## THE POLLUTION

By 1973, nearby residents knew something was wrong. Water from their wells smelled funny and was staining their laundry and sinks. Subsequent investigations by the U.S. Environmental Protection Agency (EPA) quickly confirmed the contamination of local private wells, and, as a result, connected nearby residents to the public water supply system. The source of this contamination was related to McKin's operations. Apparently, McKin was processing much of the waste it accepted for disposal by pouring or spreading it on the ground. The soil cover was so thin, as the overlying sand and gravel had long since been removed by quarrying operations, that the chemicals had only to migrate a few feet into the ground before they entered the groundwater.

## THE CLEANUP

In 1979, the Maine Department of Environmental Protection, working with the EPA and private contractors, removed more than 33,000 gallons

(124,919 L) of wastes and 165 drums of oils and chemicals from the site. Removal of all the waste was not completed until 1985, and McKin, along with 12 other sites in Maine, was added to the National Priorities List as a Superfund site. The removal actions alleviated the worst of the near-term environmental threat from the site, but surficial soils were still grossly contaminated with volatile organic compounds (VOCs), primarily trichloroethane (TCA) and trichloroethene (TCE); petrochemicals; and heavy metals, including arsenic, lead, and mercury. The concentrations of these compounds in the soil were a continuing source of contamination to the groundwater. In 1985, EPA selected low-temperature thermal desorption (LTTD) as the preferred remedy for the contaminated soil at McKin.

LTTD is an ex situ low-temperature, incineration-type process that is used on more easily treated contaminants. This technique, also called thermal desorption (TD), or soil roasting, is most commonly used to treat soil containing gasoline, solvents, and other petroleum compounds. These types of materials can be heated at relatively low temperatures in the range of 200–600°F (93.3–315.6°C), and the petroleum or other organic constituents are volatilized and driven out of the soil. The fumes are collected and treated by being either absorbed onto carbon, run through a catalytic converter, burned in a high-temperature incinerator, or, depending on their concentrations, discharged directly into the atmosphere. After roasting, the soil retains much of its original organic content, although most of its moisture is removed. With some reconditioning, the roasted soil can be reused.

If the contaminants are more complex with longer-chain hydrocarbons such as PCBs or pesticides, high-temperature thermal desorption (HTTD) can be used. In HTTD, contaminated materials are heated to 600–1,000°F (315.6–537.8°C). Both systems are designed not to change the chemical composition of the contaminants but simply to volatilize them or convert them from a solid or liquid to a gas. If oxidation occurred in either LTTD or HTTD systems, then thermal desorption would really be incineration.

At the McKin site, more than 12,000 cubic yards (9,175 m<sup>3</sup>) of contaminated soil was excavated, passed through a coarse grate or sieve, and fed with some water into a rotating cylindrical drum seven feet (2.1 m) in diameter and 28 feet (8.4 m) long. Hot air heated the soil in the cylinder to 400°F (204.4°C). It took up to three passes through the burner for the soil to achieve the cleanup requirements. Exhaust gases from the burner were passed through a high-efficiency particulate air (HEPA) filter to remove smoky particulate, a baghouse to remove coarser



particulate, a scrubber to remove water-soluble chemicals and remaining particulate, and, finally, a carbon filter to remove trace amounts of organic chemicals. Treated soil was mixed with cement to reduce any remaining contaminant mobility, and it was redeposited at the McKin site. Costs for treating this soil totaled around \$3 million, which was paid by the companies that had sent the waste to McKin for disposal, including the *Tamano* insurers.

Soil roasters or burners can be either fixed facilities, where soil is sent either by truck or rail, or mobile facilities, which travel to the contamination. In most cases, the amount of soil has to be quite large before mobile soil burning becomes a cost-effective remedial option. The system used at McKin was a rotary dryer, which is an inclined, indirect-fired horizontal cylinder, where heated gas was mixed with the soil to desorb the contaminants. Direct-fired units apply a steady flame to the surface of the soil to desorb the contaminants.

Wastes from the *Tamano* had to be remediated twice, once after the spill and once again because of inadequate processing by the disposal company. Both public and private resources had to be committed to clean up the waste twice, with a double toll on the environment, affecting surface water and shorelines in Casco Bay and the groundwater in Gray. This led to several administrative and procedural changes by the EPA and many states regarding the management of remediation-generated wastes. Contaminated debris and material recovered from a spill or discharge now can only be sent to preapproved waste management sites. Regulatory agencies, insurance companies, or waste generators audit these facilities to ensure that they are in compliance with all environmental regulations; are not connected to organized crime; do not have ongoing, controlled releases into the environment; and have all necessary operating permits.

See also ARSENIC; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; INORGANIC POLLUTANTS; LEAD; MERCURY; OIL SPILLS; PARTICULATE; PESTICIDES; SOIL POLLUTION; SUPERFUND SITES; TCA; TCE; VOLATILE ORGANIC COMPOUND.

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**MEK (methylethyl ketone)** Although methylethyl ketone is not very toxic in comparison with many of the other pollutants, it is very widespread. In contrast, its close relation, methylethyl ketone peroxide (MEKP), is far less widespread but far more toxic. MEK is also known as 2-butanone, ethyl methyl ketone, methyl propanone, and methyl acetone; MEKP is known as 2-butanone peroxide and methyl ethyl ketone hydroperoxide. Commercial names for products containing MEKP include Butanox, Cadox, Chaloxyd, Esperfoam, Hi-Point, Kayamek, Ketonox, Lupersol, Mekpo, Permek, Quickset, and Thermacure. There are far too many products that contain MEK to list all of them. MEK has been ranked as the 208th worst environmental threat of the 275 chemicals on the 2007 CERCLA Priority List of Hazardous Substances. It has been found in 472 of the first 1,416 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where it was tested. MEKP has too little usage to be listed even though it is far more dangerous. Both compounds are described and contrasted.

#### PROPERTIES, USE, AND PRODUCTION

MEK is primarily a synthetic organic compound that occurs as a colorless liquid with a sharp, acetone-like odor. It occurs naturally in fungi, some trees, and some fruits and vegetables, as well as in tobacco smoke, volcanic emissions, and forest fires. MEKP has similar physical features, except that it is typically slightly yellow, not produced in nature, and quite explosive. MEK is primarily used as a solvent for lacquers and adhesives, for cleaning materials in electroplating, in manufacturing magnetic recording tapes, in rubber and rubber cement, and in printing inks, paints, waterproof-

ing compounds, surface coatings, shoe polish, insecticides, nail polish and nail polish remover, wood stains, varnishes, cleaning solutions, extraction solvents, and paint removers. It is used as a sterilization solvent in the medical industry, in oil dewaxing and as a synthetic agent in the pharmaceutical and cosmetic industries. MEKP is widely used in the polymer industry for curing polyester resins. It is used primarily for boat building and repair, household furniture, pressed and blown glass, transportation equipment, and in supply and stone and tile products.

MEK is a high-demand chemical with an annual production of more than 675 million pounds (307 million kg) in the United States alone in 2002. MEKP, by contrast, is a compound that has much lower production with 5.9 million pounds (2.68 million kg) produced in 1982.

### ENVIRONMENTAL RELEASE AND FATE

Both MEK and MEKP are primarily released into the environment as point source pollutants, if from anthropogenic sources. They are inadvertently released from manufacturing, transport, and storage facilities as spills and leaks. Natural MEK and that from automobile exhaust and smoke are largely released as nonpoint source pollutants. Most MEK winds up in the atmosphere from both exhaust and smoke, and through its ready evaporation. The removal half-life of MEK in the air is 2.3 days as the result of reactions with photochemically produced hydroxyl radicals. It may also be removed by direct photolysis, with a half-life of 15.4 hours, and by precipitation washout. If it is released into water, the vast majority of MEK evaporates, and the rest is broken down by microorganisms in about two weeks. Most MEK released into soil also evaporates, but that which does not is highly mobile. Very little adheres to soil particles, leaving most to leach into the groundwater system or be broken down by soil microbes. MEK has been shown to inhibit the germination of lettuce seeds and wheat seeds by 50 percent or more. It is also toxic to the Caribbean fruit fly and somewhat toxic to other insects. It has long-term toxicity to aquatic life but is otherwise relatively benign. There is very little known about the release and fate of MEKP, but it is generally assumed to behave similarly to MEK in terms of interactions with air, soil, and water.

Annual releases of MEK into the atmosphere in Canada increased from 3,692 tons (3,356 metric tons) in 1993 to 4,872 tons (4,429 metric tons) in 1997.

### HEALTH EFFECTS FROM EXPOSURE

Both MEK and MEKP show a variety of adverse health effects, with the latter far more toxic. Acute exposure to MEK produces nose and throat irritation through inhalation and effects on the central nervous system such as intoxication, nausea, headache, dizziness, sleepiness, fatigue, and confusion through both ingestion and inhalation. At extreme concentrations, symptoms can be loss of consciousness, pulmonary edema with lung exposure, respiratory failure, cardiac arrest, and death. It is also a moderate to severe eye irritant and a skin irritant. Long-term chronic exposure can result in numbness in the fingers and toes, decreased nerve conduction, chronic headaches, dizziness, dermatitis, gastrointestinal distress, loss of appetite, weight loss, and muscle atrophy. Laboratory animals showed minor effects on the brain, liver, kidney, and spleen, as well as changes in blood chemistry. There is also some evidence of fetal toxicity and adverse developmental effects. It requires very high concentrations of MEK alone to produce these adverse health effects. MEK also appears to have a metabolic interaction with n-hexane, carbon tetrachloride, chloroform, and methylbutyl ketone, enhancing their neurotoxicity significantly, as well as potentially damaging the liver and lungs. MEK is classified in group D, not classifiable as to being a human carcinogen.

MEKP causes much more severe symptoms at much lower dosage than MEK. Taken internally, MEKP causes chemical burns of the gastrointestinal tract, scarring of the esophagus, hyperemia of the lungs with hemorrhaging, pulmonary edema, and mild liver and kidney damage. Through inhalation, it causes irritation of the nose and throat, labored breathing, abdominal pain, vomiting, diarrhea, and many of the symptoms produced by ingestion. Contact with vapors can cause irritation of the eyes and skin. Higher dosage typically results in coma and death through cardiac arrest, hepatic failure, and other complications. It can also cause permanent damage to the eye and, through contact with liquid, even blindness. Long-term exposure has been shown to increase the likelihood of malignant tumors in many locations of the body.

### REGULATIONS ON HUMAN EXPOSURE

Although the EPA does not have any guidelines for MEK or MEKP in water under the Safe Drinking Water Act, the EPA and other federal agencies have a variety of other regulations on both compounds. The EPA requires the reporting of discharges or spills of 5,000 pounds (2,272 kg) or more to the National Response Center. The Occupational Safety

and Health Administration (OSHA) set a limit of 200 parts per million (ppm) of MEK in workplace air (PEL) during an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set the same general limit (REL) as OSHA but with a short-term exposure limit at 300 ppm and immediately dangerous to life and health (IDLH) concentration at 3,000 ppm. In comparison, OSHA and NIOSH initially concurred on an exposure limit (PEL and REL, respectively) of 0.2 ppm in workplace air during a regular workweek, but OSHA revised their limit to 0.7 ppm. The NIOSH National Occupational Exposure Survey of 1981–83 estimated that 25,800 workers were exposed to MEKP in the United States.

See also CARBON TETRACHLORIDE; CHLOROFORM; MBK; ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE; VOLATILE ORGANIC COMPOUND; VOLCANOES.

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#### melamine (1,3,5-triazine-2,4,6-triamine)

Under normal circumstances, it is unlikely that melamine would have been included in this compilation. It is of relatively low toxicity and is not included in the 2007 CERCLA List of Hazardous Substances or any other top pollutant list. It is not tracked in Superfund sites, and there are no descriptions of it or its effects available from the National Institutes of Health, U.S. Environmental Protection Agency (EPA), or any of the other federal regulatory

agencies. The only reason that it is included is that it was identified as the culprit in a major poisoning scandal of pet foods in spring 2007. After many pets were sickened or died after ingesting pet food from China, melamine was identified as the cause, but under unusual circumstances. This entry will present the general background of melamine, and then it will describe and discuss the causes of the poisoning incident and its repercussions.

#### PROPERTIES, USE, AND PRODUCTION

Melamine is a cyanamide, a nitrogen hydrocarbon, that is synthetically produced or a metabolite of cryomazine pesticide. It does not occur naturally. Melamine was first synthesized in 1834 but was not heavily used until relatively recently. The main use of melamine is in the production of melamine resins, which are almost exclusively used in industrial applications. These resins are used in the production of laminates for tabletops, school furniture, and the like; glues, adhesives, molding compounds, coatings, paper, superplasticizers for concrete; and the addition of properties of shrink resistance, water and stain repellence, and flame retardance to cloth. Melamine itself is used also as a flame retardant in polyurethane foams, in fire retardant paints, and in the production of fertilizers, yellow pigment for inks and plastics, and some pharmaceuticals. Melamine was used as a nonprotein nitrogen for cattle from 1958, but a 1978 study concluded that it was inappropriate for health reasons, and the practice was dropped in the United States. Currently, China is the largest producer and consumer of melamine.

Melamine is also known as 2,4,6-triamino-*s*-triazine, cyanuric triamide, cyanurotriamine, isomelamine, and *s*-triaminotriazimine, among others.

#### ENVIRONMENTAL RELEASE AND FATE

Melamine is primarily released into the environment as a point source pollutant from accidental spills and leaks during manufacture, transport, storage, and disposal. Improper disposal also releases melamine to the environment. If it is released into the soil, most melamine does not readily adhere to soil particles, and, as a result, is relatively mobile. Melamine largely degrades by nitrification, which has been shown to occur at a rate of 18 percent in six to 24 weeks depending upon conditions. The removal half-life of melamine from soil through all removal processes is about two to three years, a very slow rate. Although melamine is removed from activated sludge in a wastewater treatment plant in eight hours, in natural conditions, it is very slow to be

removed from surface water. Melamine is removed from air by fallout and washout by precipitation. The toxicity of melamine to mammals and aquatic organisms is considered low.

The NIOSH 1981–83 National Occupational Survey estimates that 44,648 workers were exposed to melamine in their place of work.

### HEALTH EFFECTS FROM EXPOSURE

Melamine is considered to be of low to very low toxicity. Acute exposure may produce irritation of the eyes, skin, and mucous membranes. Long-term exposure can result in dermatitis, weight loss, elevated fluid intake, chronic inflammation of the kidneys, ulceration and hyperplasias of the urinary bladder, development of urinary bladder stones, calcareous deposits (and stones) in the kidneys, and possible reproductive effects. The International Agency for Research on Cancer placed melamine in group 3, not classifiable as to its carcinogenicity to humans. Tests on laboratory animals, however, produced in some species an increased incidence of cancer of the bladder. The problem with all of these tests is that the doses required to produce the adverse health effects are far greater than any environmental levels and, in most cases, even higher than industrial exposures. It was further found that addition of table salt to the diet would reduce the incidence of cancer from melamine exposure.

### 2007 PET FOOD INCIDENT

In March 2007, pets across America became deathly ill. They stopped eating and experienced pain with symptoms of kidney failure. Their illness was quickly traced to pet food imported from China. At first, it was thought that wheat gluten filler was the culprit, but melamine was discovered in the food and in their waste. By mid-March, at least 14 animal deaths and 14,000 cases of sickness were traced directly to this food poisoning. Many more could have occurred but were not reported. As a result, more than 60 million cans of animal food were recalled. The first question asked by investigators was how melamine, which was produced by processing of coal in China, wound up in pet food. As it turned out, industrial melamine scraps are added to many kinds of animal food in China largely as filler or a source of nitrogen. An overabundance of industrial melamine scraps in China resulted in the lowering of prices. The lower prices presented an opportunity for pet food companies to increase profits by using the melamine as filler. The second question is how such a normally relatively nontoxic substance as

melamine could have caused the acute health crisis that it did. The apparent answer is that melamine can react with cyanuric acid to form a salt called melamine cyanurate, which is apparently far more dangerous than either of the reactants. It is thought that this salt and the combination of melamine and other compounds may work synergistically to be far more dangerous to the health of the animals than the cumulative effects of the compounds by themselves. The public outcry and recall of the products caused tension between China and the United States. China turned away several cargo shipments of food from the United States in retaliation, claiming that they were tainted and unfit for human consumption.

See also ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION.

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**mercury** Mercury is an inorganic element that is designated as a heavy metal and a contaminant-pollutant of great concern, ranking number 3 on the 2007 Priority List of Hazardous substances. Although there are numerous natural sources of mercury, as well as mine spoils, that can be dangerous to extremely dangerous, it is the manufactured sources that are of greatest concern. There are good historic records of mercury toxicity in humans, especially among hatters, who were exposed to high levels through wool felt processing. The “Mad Hatter” in Lewis Carroll’s *Alice in Wonderland* has now become the most famous example, albeit fictional, of the effect of mercury on the nervous system. A more sobering example was provided by the large industrial emissions of mercury into the harbors of Japan near Minamata in the 1950s, causing widespread mercury poisoning in fishing villages. Even metropolitan areas were affected by this poisoning. There was another poisoning event in Iraq, when people began consuming processed grain intended for planting that had been treated with a methylmercury-based fungicide, a common practice. Although mercury is ever more tightly regulated and controlled



in the United States, for the foreseeable future, it remains a serious health threat. Mercury has been found in 714 of the first 1,467 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List), a very high percentage.

### PROPERTIES, USE, AND PRODUCTION

Mercury is a naturally occurring inorganic element that is present in rocks and soils throughout the Earth. Mercury occurs in three forms: metallic mercury; inorganic mercury, typically called mercury salts; and organic mercury, or organomercurials, and most commonly, methylmercury. Pure metallic mercury is the only liquid metal (and emitting mercury vapor) at room temperature, but many mercury compounds, both inorganic and organic, are solids. It is mined primarily as the mineral cinnabar and refined to usable form. There is no current mine production of mercury in the United States, but it is often imported. As much as 248 tons (225 metric tons) of mercury was imported in 2006, which continues a slight increasing trend since 2002, with the exception of 2003 and 2004, when only 50.6 and 55 tons (46 and 50 metric tons), respectively, was imported. Imports are primarily from Chile (30 percent), Peru (26 percent), Australia (20 percent), and Germany (12 percent). A big source of mercury, however, is reclamation and recycling of old products that contain mercury. In the past, mercury was used for mining, industrial applications, fungicides, batteries, paints, thermometers, barometers, mercury vapor and fluorescent lamps, medical equipment, and numerous medicines, computers, thermostats, switches, dental amalgam, and automobile convenience switches among other products. It is primar-

ily used in the United States for chlorine-caustic soda production, but also for batteries, cleansers, fireworks, pesticides, and skin creams and soaps.

### ENVIRONMENTAL RELEASE AND FATE

It is estimated that more than 150 tons (136 metric tons) of mercury is released into the environment each year from a variety of industrial sources. The single largest sources of environmental mercury are coal-fired electric power plants, producing nearly one-third of all mercury emissions in the United States, although some estimates of mercury emissions from these sources are much higher. The mercury is an impurity in the coal in very small amounts that is released into the atmosphere during burning. Through this widespread dispersion of mercury from the numerous coal-fired power plants burning increasing amounts of coal as the price of oil escalates, mercury contamination is becoming an even more serious problem. The situation is exacerbated because most U.S. power plants are exempt from the pollution controls of the Clean Air Act; in addition, mercury emissions are not specifically regulated. Formerly, when houses were heated with coal and coal-fired steam locomotives were the main source of transportation, coal emissions were a worse problem, although they were mainly confined to large cities.

The second largest sources of mercury emissions to the environment are incinerators, producing nearly 29 percent of total mercury emissions: Municipal waste incinerators produce about 18.7 percent of the emissions, and medical waste incinerators produce the remaining 10.1 percent. Items containing mercury are the source of this waste, although legislation is gradually reducing the amount of mercury found in common materials, and that reduction will in turn reduce mercury in the emissions. Incineration is regulated by the EPA. Coal-fired industrial, commercial, and residential boilers are the next greatest source of environmental mercury, producing about 17.9 percent of total emissions. Coal-fired residential boilers are rare in the United States but relatively common in some countries.

Industrial plants can also produce significant amounts of mercury. Chlorine production by plants that use the mercury cell process are the greatest single source, producing 4.5 percent. Dust emissions from cement plants also release mercury into the environment. Although the United States has significantly reduced or eliminated mercury content in common items such as thermometers and fluorescent lights, many other countries have not. Even in the United States, many automobile parts, appliances,



**Victim of mercury poisoning in Minamata, Japan, ca. April 1993—local seafood contaminated by industrial wastewater contained methylmercury compounds** (© Michael S. Yamashita/CORBIS)

and electronics, and some heavy equipment still contain mercury. Even some old sources of mercury persist in the modern environment. To separate gold ore from gangue minerals, the gold mining industry used vast quantities of mercury, most of which was dumped into streams and was deposited in the sediments. Even though the process was abandoned long ago, the mercury persists in the environment.

Mercury emissions fall out or are washed out of the atmosphere and deposit in soils, sediments, and bodies of water. Much of the deposited mercury can be washed into streams during precipitation events. Metallic and inorganic mercury are toxic even in small quantities. Even more hazardous is methylmercury, which is an industrial emission product or is formed in water, when certain bacteria convert mercury salts into it. Methylmercury is an extremely powerful neurotoxin that is very persistent in the environment. Methylmercury bioaccumulates in plankton and insects and works its way up the food chain to fish, amphibians, reptiles, birds, and mammals. The health effects to aquatic life include immune and endocrine damage to freshwater fish such as trout, perch, and pike. Loons in Canada and New England eat these fish and have been found also to have elevated methylmercury levels. They suffer behavioral and reproductive problems. Other species higher up the food chain, including ducks, mink, otters, raccoons and alligators, have shown the effects of methylmercury, as well. In one case an endangered Florida panther died of mercury poisoning. The most toxic form of mercury is dimethyl mercury, a single drop of which on the skin can kill a person.

Marine animals are also exposed to methylmercury. Sharks have been documented to contain high levels of methylmercury, as have common seafood species such as tuna and swordfish and gamefish such as king mackerel. The most publicity that mercury has gained as a threat is through its presence in tuna and swordfish. A national educational program has alerted Americans to the danger of eating too much of these fish species, making mercury one of the most well-known inorganic pollutants.

### HEALTH EFFECTS FROM EXPOSURE

Humans are at the top of the food chain and, as such, are highly susceptible to the biomagnification of methylmercury contamination. In high concentrations, it affects humans by outright poisoning, but its primary effect is its damage to the human central nervous system through its function as a potent neurotoxin. It has also been found to damage the cardiovascular system, the immune system,

and several other physiological systems to a lesser extent. In children, even low concentrations of mercury can damage the developing brain; the younger the child, the worse the effects. They can develop deficiencies in IQ, attention deficit problems, and motor function issues. Unborn children are even more prone to problems, and, as a result, expectant mothers must be very careful about their seafood intake. In 2005, the National Institutes of Health estimated that one woman in 12 in the United States has more mercury in her blood than is considered safe by the EPA. Consequently, between 300,000 and 600,000 children born each year could be at risk for adverse neurodevelopmental effects from exposure to mercury.

Acute exposure to high levels of metallic mercury vapor in the air can damage the lining of the mouth and irritate the lungs or cause nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation. Long-term exposure to mercury vapors and methyl mercury primarily damages the kidney and brain and causes personality changes, tremors, vision problems, hearing loss, loss of sensation and muscle coordination, and difficulties with memory. Long-term chronic exposure of laboratory animals to mercury salts and methylmercury produces kidney damage, elevated blood pressure and heart rate, stomach problems, immune system damage, nervous system damage, and damage to a developing fetus, potentially causing spontaneous abortion. Long-term exposure also results in an increase in tumors of various kinds; however, mercury is not regarded as a carcinogen at this time.

### REGULATIONS ON HUMAN EXPOSURE

In 1994, the EPA found mercury to be a hazardous pollutant that must be regulated under the Clean Air Act. The EPA and Food and Drug Administration (FDA) limit inorganic mercury to two parts per billion (ppb) parts of water in drinking water under the Safe Drinking Water Act. They further recommend that the level of inorganic mercury in rivers, lakes, and streams be no more than 144 parts mercury per trillion (ppt). The FDA has set a limit of one part per million (ppm) of methylmercury in seafood products and seeds sold through interstate commerce. The Occupational Safety and Health Administration (OSHA) has set a limit of 0.1 milligram of mercury per cubic meter of workplace air for organic mercury and 0.05 milligram per cubic meter for metallic mercury vapor during an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) limits metallic

mercury vapor in workplace air to 0.05 milligram per cubic meter during a 10-hour-workday, 40-hour workweek.

In 2000, the EPA further decided that mercury from power plants is a risk to public health. Normally, they would have applied existing air-toxin regulations to the problem, which would have reduced power plant emissions by 90 percent within three to five years. Upon entering office, however, President George W. Bush ordered a reinvestigation of the issue. In 2005, a new regulation plan was announced using “cap and trade” market mechanisms that permit trade of pollution rights instead of mandating emission controls. The plan is designed to reduce mercury emissions by 70 percent by 2018, but the Congressional Research Service estimated that such a reduction under this program would not occur until at least 2030.

See also INORGANIC POLLUTANTS; PARTICULATE; POINT SOURCE AND NONPOINT SOURCE POLLUTANT; SUPERFUND SITES.

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**methoxychlor** Dichlorodiphenyltrichloroethane (DDT) was the most widely used pesticide in the world until it was banned in the United States in 1972. To fill this great gap, there was a rush of other pesticides to the market to replace it. One of the more successful of these replacement pesticides has been methoxychlor, the production and use of which boomed during the 1970s and early 1980s. It even outlasted many of the other DDT replacements, which were subsequently banned during the 1980s and 1990s for similar negative ecological and public health effects. All pesticides, including methoxychlor, are designed to harm or kill organisms and, consequently, are not particularly friendly to the natural environment. In recent years, the use of methoxychlor has declined, as new advanced and less dangerous pesticides are developed. Methoxychlor is also known as Chemform Methoxychlor, Dianisyl methoxychlor, Dimethoxy-DT, DMDT, ENT 1716, Higalmetox, Marlato, Methoxide, Methoxychlor, Methoxy-DDT, NCI-00497, OMS-466, and Prentox. Methoxychlor has been ranked as the number 61 worst environmental threat of the 275 chemicals on the 2007 CERCLA Priority List of Hazardous Substances, and it has been found in 58 of the first 1,613 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where it was tested.

#### PROPERTIES, USE, AND PRODUCTION

Methoxychlor is a synthesized organic chlorinated hydrocarbon and classified as a diphenyl alkane insecticide. In its pure form, it is a colorless to pale yellow crystalline solid with a mild fruity or musty odor. It has been available in several forms, including technical grade concentrate, wettable powder, dust, granules, emulsifiable concentrate, and pressurized spray. It is primarily effective on houseflies, mosquitoes, cockroaches, chiggers, various field crop insects, and insects that infest stored grains. It is registered for use on 85 different crops including numerous fruits and vegetables, soybeans, nuts, and alfalfa, as well as forests and ornamental plants.

It has been used for insect control near barns and in greenhouses and for landscape maintenance and residences. It is also used to kill parasites on dairy and beef cattle, as well as pets.

Production of methoxychlor greatly increased in 1972 when DDT was banned. By the late 1970s and early 1980s, production peaked at more than 5 million pounds (2.3 million kg) but then decreased solidly through 1986, when usage was 500,000–900,000 pounds (227,272–409,090 kg) per year. In the early to mid-1990s, usage was down to 300,000–500,000 pounds (227,272–136,363 kg) annually, and it has never recovered.

### ENVIRONMENTAL RELEASE AND FATE

Compared with its predecessor, DDT, methoxychlor is much less dangerous to the environment by virtue of its generally lower toxicity and lower persistence. As are most other pesticides, it is foremost purposefully released to the environment as a non-point source pollutant, either sprayed onto crops and plants or applied to soil and seeds. Some is released into the air during spraying, but because it does not evaporate readily, very little vapor is released. The breakdown of vaporized methoxychlor is primarily through photolysis with a removal half-life estimated at one to 11 hours. The only way it can be widely distributed is by attaching itself to dust particles and being carried by the wind, either settling by gravity or being washed out by precipitation. It has even been detected in arctic snow, but its levels there are extremely low.

Upon its release into the soil, methoxychlor primarily binds tightly to particles in the top few inches of the surface, depending upon the chemistry and condition of the soil. Under aerobic conditions, it is quite persistent with a removal half-life of longer than 100 days through chemical reactions and biodegradation. In some instances, residues have been found up to 18 months after application to agricultural fields. Anaerobic biodegradation, by contrast, is much quicker, with a removal half-life of less than 30 days. The amount of methoxychlor leached into the groundwater is generally small; however, water from a number of wells in New Jersey has been found to have minor amounts of it. The metabolites of methoxychlor are equally dangerous and much more soluble.

Methoxychlor is not particularly soluble in water and is removed quickly by evaporation and chemical degradation. Melting snow and storm runoff, however, can wash away soil particles to which methoxychlor is adhered. These particles can be transported into surface waters and be carried in suspension.

Several rivers in the United States have been found to have very low levels of methoxychlor, including the Niagara River in New York and the James River in Virginia. The particles eventually settle into the sediment, where they are broken down with a removal half-life ranging from 37 to 46 days, depending upon chemistry, microorganisms, and physical conditions.

Methoxychlor has variable ecological effects. It is nontoxic to bees, slightly toxic to birds and mammals, but highly toxic to aquatic organisms and insects. It bioconcentrates moderately in aquatic organisms. Fish, depending upon the species, can concentrate it from 138 to 8,300 times ambient levels. Mussels, however, were found to have bioconcentration factors as high as 12,000 times ambient levels.

### HEALTH EFFECTS FROM EXPOSURE

In general, methoxychlor has been considered to be a good replacement for DDT for its health effects, as well as its effectiveness as an insecticide. The EPA has designated it as class IV in terms of its toxicity, indicating that it is only slightly toxic to humans. Most of its adverse health effects were observed in laboratory animals, rather than humans. Symptoms of acute exposure to methoxychlor include depression of the central nervous system in the form of headache, dizziness, and confusion, in addition to muscle weakness and diarrhea, followed by tremors, convulsions, periodic and continuous seizures, and, with increasing dosage, ultimately death within 36–48 hours by respiratory failure and brain paralysis. Symptoms of long-term chronic exposure at low doses in laboratory animals have included prostate, kidney, and liver damage; reduced weight; and death within 45 days, but more commonly numerous and severe reproductive effects. Decreased fertility of up to 100 percent was discovered in laboratory animals in some studies. Maturation of both male and female reproductive organs was found to be retarded and included accompanying hormonal effects. Genetic damage was permanent and, in some cases, was even passed on to subsequent generations. Birth weights of offspring were reduced, and skeletal deformities and lung problems were common.

Methoxychlor is not classified in terms of its human carcinogenicity by both the EPA and the International Agency for Research on Cancer. The general opinion of regulatory agencies is that it is not carcinogenic. There are, however, several studies that found increased incidence of cancer of the liver, testicles, ovaries, bones, and skin in a variety of laboratory animals. There was even a report of increased leukemia in humans. In contrast, there are



at least as many studies that found no connection of methoxychlor with cancer of any type. This apparent enigma has caused great controversy about the relative safety of methoxychlor.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies limit workers' and the general public's exposure to methoxychlor because of these health effects. The EPA set the limit of methoxychlor in drinking water at 40 parts per billion (ppb) under the Safe Drinking Water Act, and the Food and Drug Administration limits bottled water to the same levels. The Occupational Safety and Health Administration (OSHA) set a limit of 15 parts per million (ppm) of methoxychlor in workplace air (PEL) during an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set the immediately dangerous to life and health (IDLH) concentration at 5,000 ppm. The EPA also limits the amount of methoxychlor in some agricultural products. In 1995, California banned the use of methoxychlor.

See also BIOACCUMULATION AND BIOMAGNIFICATION; DDT; ORGANIC POLLUTANTS; PESTICIDE; POINT SOURCE AND NONPOINT SOURCE POLLUTANT; SUPERFUND SITES.

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**methylene chloride** Methylene chloride, also known as dichloromethane, is an organic compound that was widely used in both industrial and consumer applications until health concerns curtailed much of its use. One of its more notable uses was in hairspray, where human exposure to it is very high as a result of its method of application and its widespread use. It was found to be at dangerous levels in the ambient air of many beauty salons, spurring part of the regulatory action to limit its use. Methylene chloride has been designated the 80th worst environmental threat of the 275 compounds on the 2007 CERCLA Priority List of Hazardous Substances. It has been found in 882 of the first 1,569 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List), a very high percentage. It is the physical and chemical characteristics of the chemical that make it so dangerous to public health.

### PROPERTIES, USES, AND PRODUCTION

Methylene chloride is a synthesized organic chlorinated hydrocarbon in the family of saturated aliphatic halogenated compounds. It occurs as a colorless volatile liquid with a sweet odor similar to chloroform. Methylene chloride is used in a variety of applications including its main use in paint removers (30 percent); in formulated products (24 percent) such as adhesive (especially for furniture), solvent, spray paint, and lubricant; in chemical processing (18 percent) for thermoplastics, photographic film, plastic molding, and as an extraction agent for pharmaceuticals and vitamins and a coating; in the manufacture of soft polyurethane foam (15 percent); and as a metal cleaner and degreaser (4 percent). The remaining 9 percent is found in a variety of applications including an extraction agent for spices, oils, fats, waxes, and caffeine in coffee and tea. It is also used in many consumer items such as spray shoe polish, water repellent, spot remover, wood floor cleaners, contact cement, super glue, spray adhesive, adhesive remover, silicone lubricant, electronic cleaner for televisions and videocassette recorders, wood stains, varnishes and finishes, paint thinner, paint remover, aerosol spray paint, aerosol rust remover, outdoor water repellent, trans-

mission cleaner, battery terminal protector, brake cleaner, and gasket remover. Previously, one of its many applications was as an insecticidal fumigant for strawberries, citrus, and various grains.

Methylene chloride was first synthesized in 1840 but not widely available until the 1940s, when it was introduced as a less flammable solvent than the currently used solvent at the time. Its production and use have varied over the years, increasing by an average of 3 percent between 1970 and 1983 before decreasing by 1–2 percent through 1990. The decrease began when it was suspected to be a carcinogen, and bans in such products as hairspray (banned in 1989 by the Food and Drug Administration) were imposed. The domestic production in 1994 was 403 million pounds (183 million kg) but declined to about 300 million pounds (136 million kg) by 2000.

### ENVIRONMENTAL RELEASE AND FATE

Methylene chloride enters the environment mainly as a point source pollutant from industrial release, spills, and leaks during transport and storage or from improper disposal. It is primarily released into the air through evaporation and less commonly into water and soil. The breakdown chemical reaction is 90 percent to carbon dioxide, which is not dangerous. In air, methylene chloride is broken down by photolysis and reaction with photochemically produced hydroxyl radicals. The removal half-life from air ranges from 53 to 127 days, depending upon temperature, air chemistry, and sunlight. Much of the methylene chloride that is released into the water evaporates into the air. That which remains in water does not dissolve easily, and, as a result, only small amounts are found in surface water, except around waste sites. The removal half-life from water is one to six days, depending upon temperature, chemistry, and bacteria present. In soil, methylene chloride also mainly evaporates or attaches loosely to the soil particles. Some leaching occurs, as it has been found at a few locations in well water in very small concentrations. Otherwise, it is broken down by microbial action.

### HEALTH EFFECTS FROM EXPOSURE

Both acute and chronic exposure to methylene chloride produces adverse health effects. Inhalation of methylene chloride results in increased carbon monoxide and consequent reduction of oxygen in the blood. Acute exposure results in temporary impairment of hearing and vision, fatigue, drowsiness, and irritability, followed by slowed reaction times, and,

with increasing dosage, reduced hand-eye coordination. High doses can lead to unconsciousness, narcosis, and ultimately death. Chronic exposure, like that experienced by workers, results in damage to the central nervous system, marked by headaches, dizziness, nausea, loss of memory, paresthesia, tingling sensation in the hands and feet, and fainting, as well as possible liver damage. When pregnant laboratory animals were exposed to methylene chloride, an increase in spontaneous abortions, decreased birth weights, and some developmental problems in offspring resulted.

Methylene chloride has been documented in laboratory animals to produce an increased incidence of cancer of the liver, lungs, and salivary glands, and benign mammary gland tumors. It was for this reason that the EPA classified methylene chloride in group B2, as a probable human carcinogen. Additionally, methylene chloride has been labeled as reasonably anticipated to be cancer causing by the Department of Health and Human Services and a possible human carcinogen by the World Health Organization and International Association for Research on Cancer (group 2B).

### REGULATIONS ON HUMAN EXPOSURE

As a result of the danger to public health, federal agencies limit workers' and the general public's exposure to methylene chloride. The EPA set the limit of methylene chloride in drinking water at five parts per billion (ppb) under the Safe Drinking Water Act. They also require that any environmental release of 1,000 pounds (454 kg) or more be reported to the National Response Center. The Occupational Safety and Health Administration (OSHA) has set a limit of 25 parts per million (ppm) of methylene chloride in workplace air (PEL) during an eight-hour-workday, 40-hour workweek and a short-term exposure limit (125 ppm). The National Institute of Occupational Safety and Health (NIOSH) limits methylene chloride in workplace air to 75 ppm during a 10-hour-workday, 40-hour workweek in the presence of carbon monoxide at concentrations of 9.9 ppm or more. They further set the immediately dangerous to life and health (IDLH) concentration at 2,300 ppm. The National Occupational Hazard Survey conducted by NIOSH in 1972–74 estimated that more than 2.5 million workers were exposed to methylene chloride. In 1987, the EPA estimated exposure of more than 1 million workers.

*See also* CARBON MONOXIDE; ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**methyl parathion** Methyl parathion is another of the organochloride insecticides that have been reported in the news because of the many health problems it has caused. It is especially well known for poisoning incidents from improper handling in developing countries, especially in Central and South America. There were 1,243 reported poisoning incidents involving methyl parathion in 1982–91 in Oarana State, Brazil, alone. The United States, however, has not completely escaped poisoning incidents by methyl parathion. There were several criminally negligent incidents in the mid-1990s in Ohio, Mississippi, and Louisiana that received media attention. The cases in Mississippi and Ohio in particular involved the spraying of 1,500 homes and businesses with methyl parathion by unlicensed operators. As a result, more than 4,000 people had to be relocated in temporary accommodations, and cleanup costs totaled around \$50 million. The offender in Mississippi faced a maximum of 21 years in prison and/or up to \$2.1 million in fines for the offenses but received a lesser sentence and fine. The offender in Ohio faced up to six years in prison and/or a fine of up to \$350,000 and also received a lesser sentence.

Since 1978, methyl parathion has been designated as a restricted use pesticide (RUP) by the U.S. Environmental Protection Agency (EPA) as the result of its toxicity. It is also known by several trade names including Bladan M, Cekumethion, Dalf, Dimethyl Parathion, Devithion, E 601, Folidol-M, Fosferno M50, Gearphos, Kilex Parathion, Metacide, Metaphos, Metron, Nitrox 80, Partron M, Penncap-M, and Tekwaisa. As with most pesticides, it is not a common pollutant in EPA-designated Superfund sites (National Priorities List) and has been identified

in 16 of the first 1,585 sites. Nevertheless, because of its toxicity, methyl parathion has been ranked the 264th most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

**PROPERTIES, USES, AND PRODUCTION**

Methyl parathion is an organophosphate pesticide and an organic pollutant that is synthetically produced and does not occur in nature. Methyl parathion is a nonsystemic pesticide that has two forms—a pure form of white crystals and an 80 percent technical-grade solution. It is primarily available as an emulsifiable concentrate formulation and applied as a spray. It is used to control chewing and sucking insects primarily in cotton and field crops but also in a wide range of crops, including cereals such as wheat, rice, corn, and barley; and in soybeans, various types of fruits and vegetables, vines, and ornamental plants. Methyl parathion was originally developed by the German pesticide company Bayer and introduced onto the market in the early 1950s. It has been used in the United States since 1952, although it was not registered for use until 1954.

**ENVIRONMENTAL RELEASE AND FATE**

As with most pesticides, methyl parathion is primarily released as a nonpoint source pollutant that is sprayed over a large area to soil. The act of spraying releases it to the air, polluting it, and drifting spray can affect surface water, as well, as it undergoes fallout or washout in precipitation. If released to soil, methyl parathion sticks to the clay and organic particles and then is rapidly degraded by bacteria. It has a low persistence in the soil environment, with reported field removal half-lives of one to 30 days, though some laboratory studies suggest a persistence of 10 days to two months. In contrast, if large concentrations of methyl parathion are applied to soil, as in an accidental spill, complete degradation occurs only after many years. This is because it kills the soil bacteria at high concentration. It generally does not leach through the ground and enter the groundwater.

If released to water, methyl parathion breaks down quickly by the action of the water, bacteria in the water, and sunlight. It degrades very rapidly in seawater and in lake and river waters, with complete degradation occurring within two weeks to one month. The rate of degradation increases as a function of temperature and exposure to sunlight. Some laboratory studies, however, have found a much greater persistence with an estimated removal half-

life in aqueous solution of 175 days. In air, methyl parathion is broken down quickly by sunlight.

Methyl parathion is considered highly toxic to aquatic invertebrates and birds, toxic to bees, and moderately toxic to fish, cattle, and wild animals. Major bird kills, especially from improper use in Central America, have been attributed to it.

According to the EPA Toxics Release Inventory (TRI), industrial releases of methyl parathion to the environment were 1,442 pounds (655 kg) in 1995, 1 pound (0.45 kg) in 2000, and 501 pounds (228 kg) in 2006. It is not a particularly common compound in industrial applications.

### HEALTH EFFECTS FROM EXPOSURE

The reason that methyl parathion is restricted or banned completely is the number of adverse health effects it produces from exposure. For a short-term acute exposure, the first adverse effects are a bloody or runny nose, coughing, chest discomfort, and difficulty in breathing. Skin contact commonly results in sweating and involuntary muscle contractions. After exposure of any type, other systemic effects typically begin within a few minutes but may be delayed for up to 12 hours. These symptoms include nausea, vomiting, diarrhea, abdominal cramps, headache, dizziness, eye pain, blurred vision, constriction or dilation of the pupils, tearing, salivation, sweating, and general confusion. At higher doses, poisoning affects the central nervous system and produces slurred speech, loss of coordination and reflexes, weakness, fatigue, and eventual paralysis of the body extremities and respiratory muscles. Death is generally caused by respiratory failure or cardiac arrest.

For long-term chronic exposure to methyl parathion, symptoms include impaired memory and concentration, disorientation, severe depression, irritability, confusion, headache, speech difficulties, delayed reaction times, nightmares, sleepwalking, drowsiness, and insomnia. Some studies of long-term exposure of laboratory animals to methyl parathion have shown significant depression of red blood cells and plasma cholinesterase. Studies on pregnant mice showed reduced weanling survival and birth weight and suppression of fetal growth and bone formation in the offspring that survived.

### REGULATIONS ON HUMAN EXPOSURE

As a result of the many adverse health effects from exposure to methyl parathion as well as the threat to the environment, federal agencies have imposed

a variety of regulations on its usage and exposure. In addition to listing it as a restricted use pesticide (RUP), the EPA decided to cancel the registrations of emulsifiable concentrate formulations as of April 30, 1997. Further, as of December 31, 1999, methyl parathion is no longer permitted for use on foods that are commonly consumed by children such as apples, peaches, pears, carrots, peas, grapes, nectarines, cherries, tomatoes, broccoli, cauliflower, lettuce, and spinach, among many others. It was also canceled for many nonfood uses such as ornamental plants and nursery stock. Although there are no regulations under the Safe Drinking Water Act, the EPA recommends a maximal exposure of 0.3 mg per liter for 1 to 10 days for children, 0.03 mg per liter for longer-term exposure for children, and 0.002 mg per liter for lifetime exposure of adults. The National Institute of Occupational Safety and Health (NIOSH) recommends a maximal exposure in the workplace of 0.2 mg per cubic meter of methyl parathion in air for a 10-hour-workday, 40-hour workweek. Methyl parathion has been banned from usage in Indonesia, Sri Lanka, and Tanzania, and it is severely restricted in Colombia, Korea, China, and Japan.

See also ORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTANT; SUPERFUND SITES.

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**Meuse Valley disaster Belgium (December 1–5, 1930) Air Pollution** One of the most dramatic examples of the effects of exposure to excessive levels of air pollution on human health occurred in early December 1930 in the Meuse Valley, Belgium. This valley has experienced numerous incidents of tragedy and hardship. The navigable waters of the Meuse River, combined with plentiful deposits of valuable coal, have made its 15-mile (24.1-km-) long course one of the most important industrial regions of Europe. This economic importance, combined with the strategic location between France and Belgium, have made the valley a battleground numerous times since the 13th century. More recently, the movement of German troops toward the Meuse River in the closing days of World War II played a key role in the Battle of the Bulge, which took place nearby.

### BACKGROUND

In 1930, the Meuse Valley was home to coke ovens, blast furnaces, zinc smelters, fertilizer factories, and sulfuric acid plants. These companies provided the region with thousands of high-paying jobs and helped support a thriving national economy in Belgium. The 9,000 residents not only worked on small farms and in villages raising crops and livestock, but also were steelworkers, glassblowers, and munitions manufacturers. The 12-mile (19.3-km) part of the valley between the towns of Liège and Huy was the most developed, but also the narrowest, bordered on both sides by cliffs rising 270–350 feet (82.3–106.7 m) above the valley floor.

This restricted geography caused in the Meuse Valley to be plagued with almost constant air pollution. At the time, most people considered pollution an unavoidable consequence of industrial prosperity, and little pressure was placed on local industries to reduce emissions or even consider the impacts of releasing enormous quantities of particulate, sulfur dioxides, and other noxious gases into the air. The residents of the Meuse Valley were accustomed to some of these consequences. In 1911, many cattle reportedly died as a result of air pollution, and in the central valley town of Engis, windowpanes and light bulbs were etched or frosted by an airborne release of hydrofluoric acid.

### THE AIR POLLUTION DISASTER

Between Monday, December 1, and Friday, December 5, 1930, a winter temperature inversion resulted in an industrial disaster that, for the first time, focused modern scientific and medical attention on

the public health impacts of air pollution. It was a cool evening in the Meuse Valley, with temperatures just above freezing, a weak easterly wind (less than two miles per hour [3.2 km/h]), and relatively high barometric pressures. Above the valley walls, however, a warm front was carrying in a dense, humid air mass that formed a thermal blanket over the Meuse Valley, resulting in a thick fog and greatly reducing the movement or dispersion of polluted air out of the valley. During this time, factory operations were on the usual weekday schedule, and the industrial stacks and chimneys continued to exhaust pollutants into the now-stagnant atmosphere.

The first signs of a problem began on December 3, when hundreds of people almost simultaneously throughout the entire valley began to experience respiratory problems. The most common symptoms included laryngeal irritation, uncontrollable coughing, chest pain, and difficulty in breathing. More severe cases included cyanosis, asthmatic breathing, nausea and vomiting, and even pulmonary edema. Sixty people died on December 4 and 5, and the total deaths for the entire event were 63. Of these, 56 were in the eastern half of the valley, and only seven were west of the midvalley village of Engis. The mortality rate over the period was 10.5 times normal. The elderly were at most risk; the average age of those who died was 62. Children and people who had other complicating medical conditions, such as cardiac or respiratory disease, also were disproportionately affected. By December 5, weather conditions changed, and the fog began to dissipate, fresh air began to make its way into the valley, and the immediate public health crisis passed. Autopsies of 15 of the dead showed excessive amounts of soot in the lungs.

### THE AFTERMATH

The Belgium government commissioned a panel of experts to study and determine the reasons for the disaster. The panel included experts in meteorology, toxicology, forensic science, and chemistry. They reviewed and evaluated a wide variety of factors that could have contributed to the catastrophe. These potential factors ranged from a viral epidemic introduced by the cold weather, to the secret testing of wartime chemical gases to toxic sand blown in from the Sahara. After a year of study, investigators found that the deaths and other related medical complaints were due to a local irritant present in the outside air. This irritant was a concentration of sulfur dioxide (SO<sub>2</sub>) in the air in the range of 100 mg/m<sup>3</sup>. Safe levels of SO<sub>2</sub> exposure are in the 20–30 mg/m<sup>3</sup> range.

Some of this SO<sub>2</sub> reacted with water vapor to form dangerously high levels of sulfuric acid in the air.

The SO<sub>2</sub> was produced by the domestic and industrial burning of coal in the valley, which was concentrated in the ambient air by the combination of a temperature inversion and the natural geography of the Meuse Valley. Up to 130,000 pounds (59 metric tons) per day of SO<sub>2</sub> was estimated to have been produced in the Meuse Valley through the burning of coal. The government's report also indicated that some of the other industrial pollutants present in the atmosphere, particularly zinc and iron from metal smelters, probably increased the amount of sulfuric acid production. Another contributing factor was the absorption of the SO<sub>2</sub> onto very small particles of soot, which were able to work their way deep into the lungs and bronchial passages.

As an air pollution event, the Meuse Valley catastrophe had public health consequences that reverberated across Europe. It was the first time that nonoccupational exposure to air pollution was directly connected to the deaths of people living near the factories and mills where the SO<sub>2</sub>, hydrofluoric acid, and other toxic contaminants were being released. The panel of experts retained by the Belgium government did an excellent job of scientifically dismissing nonindustrial sources of the pollution such as damp moist air in the fog, causing flu or some other sort of viral epidemic. A subsequent commission, also formed by the Belgium government, recommended that a central authority assume responsibility for the issuance of permits to discharge pollutants into the air. This central commission would be less susceptible to local political pressures and would have the ability to monitor air quality in the vicinity of the plants it had permitted. Little was done, however, to implement these recommendations. Air pollution, however, was now on the agenda of the scientific community, and the days of freely discharging contaminants into the atmosphere were coming to an end.

One group of public health officials who closely followed the events in the Meuse Valley were those in Great Britain. For years, cities such as London and Glasgow had suffered through notorious "pea soup" fogs caused by a combination of extensive coal burning and the influx of cool, damp air from the North Sea. London's geography had prevented these fogs from lingering, but officials were concerned that, given the right set of meteorological conditions, a Meuse Valley-like disaster could occur. In 1952, it did, the London Killer Fog.

See also AIR POLLUTION; LONDON "KILLER FOG"; PARTICULATE; SULFUR DIOXIDE; TEMPERATURE INVERSION; ZINC.

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## Milan Army Ammunition Plant Milan, Tennessee (1987–present) Soil and Water Pollution

In 1941, the Department of Defense began construction of a munitions facility about 100 miles (160.9 km) northeast of Memphis, Tennessee, and just a few miles east of the small town of Milan. As World War II approached, the pace of construction quickened, and in January 1942, the new facility opened. By the end of the war, the Milan Army Ammunition Plant (Milan AAP) employed 10,000 people, who operated 14 process lines and were responsible for the loading, assembly, storage, testing, packaging, and shipment of demolition charges, mortar rounds, artillery projectiles, grenades, and various types of small arms ammunition. It was shut for a short time at the end of World War II but reopened during the Korean conflict and has remained operational ever since. Currently, Milan AAP has about 500 employees and is made up of 1,400 buildings and six active production lines on more than 22,000 acres (8,903 ha) of land. Production lines, along with administrative, maintenance, and other support activities, are contained within about 500 acres (202.3 ha). The remaining land area is needed to allow for safe (buffer) distances between local residents and explosive and munitions storage and testing areas.

The manufacturing, processing, and demilitarization or destruction of explosives require large amounts of water, both in formulating the compounds and in cleaning and washing vessels, piping, and other equipment. Currently, this wastewater is treated extensively to remove chemical and explosive residues before being discharged to a surface water body under permit conditions established by

## HEALTH EFFECTS FROM EXPOSURE TO RESIDUES OF EXPLOSIVES

Pollutant	Health Effects
RDX (1,3,5-trinitro-1,3,5-triazine)	Exposure (inhalation or ingestion) to large amounts can cause seizures. Long-term, low-level exposure effects on the nervous system have not been studied, although nausea and vomiting have been documented. EPA has classified RDX as a possible human carcinogen.
TNT (2,4,6-trinitrotoluene)	Workers exposed to high concentrations of TNT developed anemia and abnormal liver function. Long-term exposure led to severe skin irritation and cataracts. Animals involved in laboratory studies also developed blood and liver effects, including spleen enlargement and immune system damage. EPA has designated TNT as a possible human carcinogen.
HMX (Octogen or cyclotetramethylene-tetranitramine)	Little information on the adverse health effects of HMX is available. Animal studies suggest that exposure to HMX may harm the liver and central nervous system. EPA has not yet classified HMX as to its potential human carcinogenicity.
Tetryl (2,4,6-trinitrophenyl- <i>n</i> -methyl-nitramine)	Tetryl is no longer made or used but was a common World War II-era explosive. Workers handling Tetryl developed coughs, headaches, eye irritation, nosebleeds, and nausea. Their skin also became stained with a distinctive yellow color. Animal studies indicate that Tetryl damages the kidney, liver, and spleen. The EPA has not reviewed Tetryl to identify its potential to cause cancer in humans.

either the U.S. Environmental Protection Agency or the Tennessee Department of Environmental Conservation.

## POLLUTION OF THE SITE

Historical wastewater treatment processes at Milan AAP were not as efficient as the carbon-based filtering systems being used today throughout this facility's seven individual wastewater treatment plants. As a result, various explosives residues including TNT, RDX, HMX, and Tetryl contaminated soil, stream sediment, and groundwater. The primary sources of this contamination were wastewater and wash water that was released into open-topped and unlined drainage ditches and swales that led to sumps or surface impoundments and eventually emptied into intermittent and perennial surface water bodies adjacent to and flowing past the property. In particular, condensed liquids from the "O" Line operation, where high-pressure steam was used to flush TNT and TNT-RDX mixtures from munitions, was discharged into 11 unlined settling ponds, each with a 5.5-million-gallon (20.8-million-L) capacity. Sediment was periodically dredged from these ponds and stored on the ground to dry. Run-off and leachate from this sediment discharged into nearby drainage ditches, and liquid from the ponds flowed directly into surface water bodies.

Milan AAP's wastewater, like wastewater from many munitions facilities, is primarily made up of

"pink water," which is wash water associated with load, assemble, and pack (LAP) operations or with the demilitarization of munitions that have had contact with finished explosives. Pink water is actually clear and only turns pink or reddish or black, depending upon its final chemical composition, if exposed to light. The main ingredients of pink water are trinitrotoluene (TNT), which has a more characteristic red color (wastewater from TNT processing is sometimes called "red water"), and RDX. These types of explosives residues enter wastewater streams during equipment washing and during chemical neutralization of old munitions.

TNT and RDX residues are very resistant to biodegradation, volatilization, hydrolysis, and other natural transformation or breakdown processes because of their chemical composition. Once discharged into the environment, they tend to persist in soil and water. TNT is the least soluble of the high explosives, and it tends to remain present in the soil much longer than RDX and HMX. They are much more soluble and represent a significant threat to groundwater quality. Heavy metals including lead, arsenic, bismuth, copper, and others used in LAP operations are common cocontaminants at munitions facilities and can also contribute to soil and groundwater contamination.

Milan AAP's groundwater contamination occurs as a plume approximately 3,000–4,000 feet (914.4–1,219 m) long by 1,000 feet (304.8 m) wide and 140 feet (42.7 m) below the surface that has flowed

from the property and into drinking water supply wells. In addition, this groundwater contamination threatens the Memphis Sand Aquifer, which is a major source of potable groundwater for 10,000 people living in and around the city of Milan. As a result of this threat to public health, as well as other serious environmental conditions present on the site, Milan AAP was placed on the National Priorities List (NPL) as a Superfund site in July 1987, and an interagency agreement between the U.S. Environmental Protection Agency (EPA) and the Department of Defense was signed in 1989 committing both parties to conducting and managing an effective cleanup of the facility.

### THE CLEANUP OPERATIONS

One of the first steps in the remediation efforts was to control the off-site migration of contaminated groundwater. The army installed a series of pump-and-treat groundwater recovery systems that established a hydraulic barrier around the areas of the Milan AAP where contaminants are present in the groundwater. Water captured by a series of extraction wells is pumped to a treatment system where explosive residues (primarily RDX) are removed to levels below regulatory concern. Although there were some initial difficulties in making the pump-and-treat systems operational, the facility worked through these problems, and they currently are effectively preventing the movement of contaminated groundwater from the site. Approximately 85–90 percent of the contaminant plume is being captured, and modifications to the pump-and-treat system are being considered and will probably be implemented, depending upon ongoing performance.

The army also provided funds to the city of Milan to relocate and reinstall its drinking water well field. A Restoration Advisory Board (RAB) was established so that local residents; representatives of the army, EPA, the state regulatory agency; and other stakeholders can work together to develop an acceptable remedial plan for the Milan AAP.

To address soil issues, the O-Line ponds were capped so that soil and sediment in them could no longer leach metals or explosive residues into the groundwater. Other areas of contaminated soil are being excavated and treated on-site in a unique manner. In perhaps the largest test of phytodegradation, the U.S. Army Environmental Center, in cooperation with the EPA and the Tennessee Valley Authority, constructed two 2,400-square-foot (223-m<sup>2</sup>) gravel-bed wetlands. Four different types of grasses were planted in each wetland, and water containing high influent concentrations of TNT (4,000 parts per bil-

lion [ppb]), RDX, and HMX (averaging 9,000 ppb) was slowly discharged into each wetland cell. The goal was to reduce the concentrations of TNT to 2 ppb and of other compounds to less than 50 ppb. Except during a few winter months, these goals were achieved with more than 6.5 million gallons (24 million L) of explosive-contaminated water successfully treated by the system. The treatment cost using the constructed wetlands was approximately \$1.80 per 1,000 gallons (\$0.48 per 1,000 L) compared to cost of traditional treatment methods of almost \$4.00 per 1,000 gallons (\$1.06 per 1,000 L). The use of both phytodegradation and other bioremediation technologies is being expanded at Milan AAP to address both soil and sediment contamination.

Milan AAP is one of five specialty LAP munitions facilities around the country. The others—Iowa AAP, Kansas AAP, Lone Star AAP (Texas), and Lake City AAP (Missouri)—also have environmental problems, to one degree or the other, similar to the concerns at Milan AAP. The munitions produced by these plants have helped the United States defend itself for almost 70 years, and the Department of Defense, with some prodding by EPA as well as state and local stakeholders, is committed to their remediation and continued environmentally compliant operation.

*See also* AQUIFER; ARSENIC; BIOREMEDIATION; GROUNDWATER; IN SITU GROUNDWATER REMEDIATION; LEAD; SOIL POLLUTION; SUPERFUND SITES.

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### **military facilities and the environment**

Just as waging war has environmental consequences, so does preparing for war. The thousands of current and former military bases, storage depots, and weapons research facilities strategically placed across the United States and in other countries often are the sites of some of the most egregious environmental conditions yet discovered. The reasons for this are rooted not in an evil disregard for nature or an overwhelming sense of elitism, but rather in a single-minded dedication or focus on a very important mission: the defense of the United States. As Lyndon B. Johnson, 36th president of the United States, once said: “We don’t propose to sit here in our rocking chair with our hands folded and let the Communists set up any government in the Western Hemisphere.”

The location and development of military facilities, especially those built during and after World War II, were based on a variety of logistical and strategic factors such as distance from attack-vulnerable coastlines, availability of a reliable freshwater supply, access to transportation infrastructure and power, and location relative to population centers. In the 1940s, many of these bases and facilities were established when America was fighting for its very existence and the outcome was far from certain. Later, trying for 30 years simultaneously to prevent and to prepare for the threat of thermonuclear Armageddon only slightly moderated the military’s need to maintain an urgent, almost wartime attitude.

Considering the dire reason for military facilities, in choosing a site for a military base or nuclear weapons complex, the ways that bases or support facilities might adversely affect the local environment were not given much, if any, consideration. Rather, logisticians and government contractors were, by necessity and cultural predilection, single-mindedly focused on quickly and cost-effectively placing the base, depot, or research facility into operation.

Another factor that contributed to the environmental degradation is the nature of the materials used in the missions. The development, manufacture, storage, and maintenance of conventional and nuclear weapons involve the use of dangerous and hazardous chemicals. Many of the bases and facilities are large (often thousands of acres), to allow for privacy and security, rapid expansion, multiple uses, and processing and storage of large amounts of chemicals. This increases the risk of an uncontrolled release and can make it difficult to track and manage the environmental status of these materials. The veil of secrecy that hung over many of these installations also did not encourage environmental accountability.

The environmental impacts of military operations can be broadly classified into those associated with fuel storage and usage, equipment maintenance, development and testing of munitions, and land use.

### **FUEL USAGE AND STORAGE**

All the combined parts of the federal government, including the military, consume approximately 2 percent of the U.S. liquid fuel budget (oil, kerosene, gasoline, etc.), or roughly 440,000 barrels (19,987,000 L) per day. The military uses about 97 percent of this, which is more oil than any other governmental or private sector organization and more than many countries. About \$20 billion was spent by the military on oil in 2007. The U.S. Air Force is the single biggest oil consumer, using just more than 50 percent. The U.S. Navy and U.S. Marine Corps use 32 percent of the oil, and the U.S. Army uses 12 percent. “Mobility”-type fuel for aircraft, ships, and vehicles makes up about 75 percent of total consumption, with jet fuel accounting for almost 69 percent of mobility fuel.

Much of the rationale behind the creation of the U.S. Department of Energy’s Strategic Petroleum Reserve (SPR) was to ensure an adequate supply of fuel for the military in times of crisis or interruption of foreign supplies. The SPR is a collection of four artificially created caverns carved out of salt domes in Louisiana and Texas on the Gulf Coast. Its total capacity is about 700 million barrels (111,291 million L). The crude oil stored in these immense caverns thousands of feet below the surface has been used to help lower heating oil costs for U.S. consumers in times of shortage and been sold to allies in the Middle East when their supplies have been disrupted by war or political turmoil.

The use and storage of these enormous amounts of gasoline, jet fuel, marine diesel, and other liquid fuels have resulted in significant environmental impacts. Liquid fuels are stored in aboveground and underground tanks that occasionally leak, are punctured or otherwise damaged, and discharge their contents into the soil and groundwater. At many military airports, fuel is dispensed through a buried high-pressure hydrant system from a central tank farm. By simply connecting a fuel line to a dispenser, aircraft can be refueled much more quickly and supply tankers reloaded without the need for transfer from limited-capacity tanker trucks. Even a pinhole leak in the subsurface lines of a hydrant system can discharge gasoline or jet fuel into the environment.

Effects of fuel usage and storage are exemplified at the U.S. Navy’s base on Diego Garcia, an island reef, about 6,700 acres (2,711 ha), in the Indian



**Fuel storage tanks at U.S. Navy base on Diego Garcia in the Indian Ocean, midway between Africa and Indonesia** (© Reuters/CORBIS)

Ocean some 1,000 miles (1,609 km) south of India. For most of its recorded history, Diego Garcia was a quiet plantation island, producing copra nuts used to make a fine oil for lighting and machining. In the early 1970s, the navy built a small communications facility on the island, and, as the Persian Gulf countries (especially Iran in 1979) started to become more critical to U.S. strategic and economic interests, military facilities on Diego Garcia were rapidly expanded. By the time of the first Gulf War in 1991, the island was home to about 1,700 military personnel and 1,500 civilian contractors as well as a modern operating airfield.

As part of the development of the island, a hydrant refueling system was constructed to support combat and other aircraft operations. Hydrant fueling systems are made up of fuel storage in aboveground or underground tanks, distribution lines that are usually underground pipelines, fuel dispensing hydrants near aircraft-parking spots, and pumps for moving fuel from the storage containers through the pipelines to the hydrants and into the aircraft. Hydrant systems can supply fuel to four or more aircraft simultaneously, transfer-

ring fuel at rates of up to several hundred gallons per minute.

At Diego Garcia, the 18-inch- (45.7-cm-) diameter buried pipeline connecting the hydrant fuel system to its supply tanks cracked and released at least 160,000 gallons (605,666 L) of jet fuel into the subsurface before the leak was detected and repaired. The released fuel was under a concrete airport tarmac and covered approximately nine acres (3.6 ha). To recover the fuel without interfering with airfield operations, the U.S. Air Force installed an in situ bioslurping system in a grassy area near the airstrip. This system included a vacuum pump and more than 1,000 feet (0.3 km) of horizontal polyvinyl chloride (PVC) piping connected to six recovery wells. Recovery tubes were placed about one foot (30.5 cm) into the water/fuel interface zone. A vacuum pump ran continuously in each of the recovery wells. In the first month of operation, 2,000 gallons (7,571 L) of fuel was recovered and capture rates over 18 months were about 1,000 gallons (3,785 L) of fuel per month. Given the success of this system, it was expanded to a 50-well system and used at an aircraft ramp area and eventually employed to remediate the

entire nine-acre (3.6-ha) plume. More than 100,000 gallons (378,541 L) of fuel has been recovered by the bioslurping system.

Between 1985 and 2006, the U.S. military total energy consumption decreased by 60 percent, with most of that reduction resulting from increasing energy efficiency of buildings and facilities. This reflects a trend observed since 1985, when the U.S. military consumed almost 180 million barrels (490,000 barrels per day, or 77.9 million L). In 2006, its oil consumption was down to 117 million barrels (320,000 barrels per day or 50.9 million L), in spite of supporting fuel-intensive missions in Iraq and Afghanistan.

### **EQUIPMENT MAINTENANCE**

Since the 1940s, the U.S. Navy has operated and maintained a fleet of more than 87,000 surface vessels, submarines, support ships (tugs and tenders), and near-shore patrol vessels. Over that same time, the U.S. Air Force has deployed more than 100,000 aircraft. By 2007, there were approximately 1.4 million people on active military duty, with another 1.5 million on reserve status, each needing specialized equipment (weapons, trucks, electronics, etc.). The enormous size and worldwide presence of the U.S. military, often in hostile environments, require that its equipment be tested and maintained to exacting performance standards. As an indication of how important this is, in 2007 the U.S. Army spent almost \$40 billion of its \$140-billion budget on equipment operation and maintenance (O&M) programs.

Equipment maintenance, especially at bases in operation before today's heightened awareness of soil and groundwater contamination, can have serious environmental consequences. Most military-related O&M programs can be classified into three types. User, or direct, support activities include inspection, cleaning, lubrication, and minor adjustments performed by the equipment operator. When necessary, direct support maintenance is carried out by specialized teams in fixed or mobile maintenance facilities. Intermediate, or general, support is performed by unit maintenance personnel and involves recovery, evacuation, inspection, troubleshooting, and some replacement of parts and assemblies as well as maintenance involving the repair of equipment. This type of maintenance generally is performed by specialized units in fixed centers, each of which specializes in a particular type of equipment (e.g., combat vehicles or missiles). Full maintenance also is carried out by highly specialized maintenance personnel in fixed facilities. It involves the rebuilding of entire items

and renovation of major assemblies (such as motors or transmissions) for return to general stocks.

The environmental consequence of maintenance activities, especially when vehicles such as ships, aircraft, trucks, and other vehicles are involved, can be significant. Paint removal and application, engine and hydraulic system repair and refurbishing, and metalworking (e.g., to repair battle or training damage) involve the use of hazardous substances and result in the generation of hazardous wastes such as solvents, used oils, acids, and plating residues. Repairs and maintenance done in the field can result in localized ecological impacts (oil from a truck released to a stream or onto the ground). It is, however, at the fixed general support or wholesale maintenance centers where the potential for environmental damage is the greatest.

An example of long-term military maintenance activities that affected the environment occurred at Barrel Bluffs at the King Salmon Air Force Base in Alaska 280 miles (450 km) southwest of Anchorage. The approximately 730-acre (295-ha) King Salmon Air Station was built at the beginning of World War II as a military fuel and maintenance facility to help guard the Aleutian Islands. The air station also served as a control and warning site for the air defense system in Alaska during the cold war of the early 1950s as part of the North American Aerospace Defense Command, or NORAD. On the Alaska Peninsula and adjacent to Bristol Bay and Katmai National Park and Preserve, the King Salmon area developed into a major government, transportation, and service center for the commercial red salmon and recreation industries.

The state of Alaska acquired the airfield in 1959, and it now serves as a commercial airport. A massive environmental legacy, however, was left by 20 years of military operations, under close-to-wartime conditions. In addition to an extensive plume of trichloroethylene- (TCE) and petroleum-contaminated groundwater, between the mid-1940s and the mid-1960s, an estimated 500,000 drums of fuel oil, solvent residues, and other wastes generated from maintenance activities were buried in the Barrel Bluff area. Civilian housing was built in the area of Barrel Bluff, but the air force purchased the housing and relocated the residents once the extent of the contamination became known.

From 1996 through 1998, under the oversight of the U.S. Environmental Protection Agency and Alaskan Department of Environmental Conservation, the air force removed most of the near-surface containers. A \$13-million program of recontouring and capping then was initiated along with a long-term operation, monitoring, and maintenance



plan. This long-term plan requires site-access and land-use restrictions, regular inspection and maintenance, and continued operation of water-treatment and groundwater monitoring systems.

### DEVELOPMENT AND TESTING OF MUNITIONS

As the military missions have changed, and as technology has improved, the armed forces' need for a large, widespread infrastructure has significantly decreased. The military bases from which forces are trained, equipped, and deployed play an important role in ensuring mission effectiveness. These military installations and associated weapons ranges, as well as the organization and stationing of its forces, however, are constantly being reevaluated. A key component of that evaluation is BRAC, the Base Realignment and Closure Commission. In 1988, 1991, 1993, and 1995, the Department of Defense (DOD) carried out base realignments and closures through the BRAC process. BRAC allows the DOD to consider changes in threat, force structure, technologies, doctrine, organization, business practices, and plant inventory. The DOD then is able to develop base realignment and closure recommendations in a fair, consistent, and transparent manner. In 2005 alone, BRAC recommended and Congress approved closure of Fort Monmouth, New Jersey; Forts Gillem and McPherson and Naval Air Station Atlanta, Georgia; Fort Monroe, Virginia; U.S. Army Garrison-Selfridge, Michigan; Naval Station-Pascagoula, Mississippi; Naval Station-Ingleside, Naval Air Station-Corpus Christi, and Brooks City-Base, Texas; Onizuka Air Force Station, California; Galena Airport Forward Operation Location, Alaska; and almost 400 Army Reserve and Army National Guard facilities.

Once these facilities are decommissioned, the DOD remains responsible for cleaning up soil and groundwater contamination that may have been caused by their operations. BRAC-closed facilities and other such properties are known as Formerly Used Defense Sites (FUDS). The army manages the program and the U.S. Army Corps of Engineers (USACE) controls and directs related environmental cleanup activities. The scope and magnitude of the FUDS program are significant, with some 9,200 former bases and facilities identified for potential inclusion in the process and 2,700 of those requiring near-term remediation.

One of the major issues facing the FUDS program is the cleanup of environmental contamination associated with conventional military munitions testing and development. Conventional military munitions are those that are not biological or chemical agents

or nuclear/radioactive in nature. The firing of small arms can contaminate the ground with lead, and propellants and pyrotechnics from projectiles can leach heavy metals and organic chemicals into the soil and groundwater at launch and impact sites. Finally, the on-site disposal of UXO (unexploded ordnance) through burial or inefficient and often incomplete open burning/open detonation can result in both an explosive hazard and ecological damage. The following table describes some of the most common military munitions and their related environmental and health effects.

### Production Facilities

At the Badger Army Ammunition Plant in Sauk County, Wisconsin, single- and double-base propellant for cannon, rocket, and small arms ammunition was manufactured intermittently for more than 30 years. Double-base propellants consist mainly of fibrous nitrocellulose and a gelatinizer, or plasticizer, such as nitroglycerin or a similar compound (ethylene glycol dinitrate). Each base contains two active ingredients, oxygen and fuel, in the same compound. Single-base propellants are smokeless powders utilizing either nitrocellulose (gun cotton) or nitroglycerin as the only active constituent.

At the time it opened at the beginning of World War II, Badger was the largest propellant manufacturing facility in the world. Employing more than 20,000 people, the plant operated around the clock and included housing, schools, and recreation facilities for workers, many of whom spent the entire war years living on its secured grounds. Placed on standby status at the end of the war, Badger was reactivated for the Korean and Vietnam conflicts. In 1997, Badger was declared surplus property and permanent decommissioning activities began.

Facility operations resulted in extensive soil and groundwater contamination. In the late 1990s, 1 million pounds (453,592 kg) of leftover nitrocellulose was converted to fertilizer and then was applied to land to be used for livestock grazing and farming. The former open burning site at Badger was closed with soil cover in 1996. Groundwater treatment facilities treating 3,400 gallons (12,870 L) of water per minute are addressing the contamination. The treated water is being used at Badger for all water not suitable for drinking. In 1997, a former landfill was closed with a cap and a soil vapor extraction system.

As required by an RCRA Corrective Action order, environmental scientists identified 312 areas within the plant grounds that had been contaminated. The cost of the investigation and remediation is in the range of \$250 million. Solvents (carbon tetrachloride and TCE), metals (lead), and explosive wastes



**EXPLOSIVES GLOSSARY**

Type	Definition	Example
Low-Order Explosive	Produce a subsonic shock wave and almost no pressure wave. They tend to burn rather than explode.	Gunpowder, flares, pyrotechnics (fireworks), and petroleum-based bombs such as Molotov cocktails
High-Order Explosive (High Explosive)	Produces a high-speed shock wave that has a powerful blast effect. During detonation, the high explosive is decomposed into hot, rapidly expanding gas.	Nitroglycerin: a primary explosive that can detonate with little or no stimulus. Dynamite (trinitrotoluene or TNT): a secondary explosive that requires a strong shock (from a blasting cap) to detonate. Secondary explosives can be further subdivided into "melt-pour" explosives, which are based on nitroaromatics (TNT), and "plastic-bonded" explosives, which use a binder and crystalline explosive (RDX)
Blasting Agents (Tertiary Explosives)	Very insensitive to shock. Require an intermediate (secondary) explosive booster to initiate detonation	Ammonium nitrate/fuel oil mixture (ANFO) or "wet bag" explosives: used primarily in mining and construction.
Fuse	Simple detonating device that, when ignited, burns slowly and steadily from one end through an opening into the container, where it detonates the explosive charge.	On a firecracker, tissue paper extending from one end and rolled to keep the black powder in its center.
Fuze	Used in military-type munitions to detonate the explosive charge under specified conditions.	Time fuzes, contact fuzes (explode on impact or when stepped on or rolled over), proximity fuzes (activated by radar or sonar), remote fuzes (detonation initiated by an electrical impulse over a wire or by a radio wave).

**COMMON EXPLOSIVES**

Semtex	A type of general-purpose plastic explosive (mixture of RDX and PETN) that is usable over a large temperature range. Used primarily in commercial blasting. Favored by terrorists because it was easy to obtain and difficult to detect, until a special tracer chemical was added so that bomb-sniffing machines could more easily identify its presence. The government of the Czech Republic, where Semtex was developed and currently is being manufactured, controls all current sales.
C-4	Also called Composition-4, it is formed by mixing RDX in slurry form with a binder and allowing it to dry. It forms an off-white solid with a texture like that of modeling clay. It can be pressed into any desired shape and is extremely stable, requiring a blasting cap for detonation.
PETN	Pentaerythritol tetranitrate, used extensively as a military demolition charge, is one of the most powerful high explosives ever developed. When mixed with TNT, 0.5 pound (0.23 kg) can penetrate up to five inches (12.7 cm) of armor plating. PETN also is used as a vasodilator in the treatment of heart disease.
TNT	Trinitrotoluene was developed in the 1860s and is less powerful and more difficult to detonate than modern explosives. Its main advantage is that it can be melted safely using steam or hot water and poured into shell casings or other containers. TNT is very toxic and a possible human carcinogen. Exposed individuals suffer from abnormal liver function and severe skin irritation.
HMX	A plastic-bonded high-molecular-weight explosive exclusively used by the military in both tactical applications and initiation (detonation) of nuclear weapons. It also has been used as a solid rocket booster.
RDX	Research Department (composition) X is a nitroamine-based explosive with a wide variety of commercial and military uses. RDX usually is mixed with a plasticizer and serves as the basis or main ingredient for other types of explosives.

(2,4- and 2,6-dinitrotoluene, nitrates) entered soil and groundwater beneath the plant, especially in an area known as the Propellant and Deterrent Burning Grounds. These were areas where excess, surplus, or off-spec gunpowder and their ingredients were ignited to stabilize and safely dispose of them. The combustion process, however, was often incomplete, and residues remained at the surface or were covered with fill. Rainwater or snowmelt migrating through the chemical residues generated leachate, which subsequently contaminated underlying soil and groundwater.

A three-mile- (4.8-km-) long plume of contaminated groundwater migrated off-site from the Propellant and Deterrent Burning Areas and impacted local private drinking water wells. A soil vapor extraction system was installed to remove volatile organic compound (VOCs) in the subsurface. A 3,000-gallon-per-minute (11,356 Lpm) pump-and-treat system that eventually was installed captured the contaminated groundwater moving off-site and treated it to drinking water quality standard by using a combination of air stripping and carbon filtration. Monitoring data for both systems indicate high removals of VOCs from subsurface soils and groundwater and decreasing contaminant concentrations in source areas.

### Testing Ranges

The Jefferson Proving Ground (JPG) in southeastern Indiana is an approximately 55,000-acre (22,258-ha) army-run facility opened in 1940 that is about eight miles (12.9 km) north of the Indiana-Kentucky border. Until 1995, JPG tested ammunition and related weaponry. Declared by BRAC no longer necessary, JPG was closed, and in 1996 decommissioning (removal of UXO) and environmental cleanup began. When operations ceased, JPG contained almost 380 buildings, more than 180 miles (290 km) of roads, 50 miles (80.5 km) of boundary fence, and an abandoned airport with four runways.

An east-west, 268 former gun position firing line divided the base into a 51,000-acre (20,639-ha) Northern Firing Range Area and a 4,000-acre (1,619-ha) Southern Cantonment Area. The cantonment area was used for administrative support, ammunition assembly and testing, vehicle maintenance, and temporary housing of troops. As in any industrial facility in use at the time, the soil and groundwater within the cantonment area have been affected by the spillage and disposal of polychlorinated biphenyls (PCBs), petroleum hydrocarbons from underground storage tanks (USTs), cleaning solvents, and heavy metals, primarily “red lead” used as a propellant oxidant. The wastes were emptied

into pits, spread out on the ground, open-burned in designated areas, or buried in one of several on-site landfills. Proposed cleanup activities for these wastes include limited removal, institutional controls based on future anticipated commercial/industrial land use, and continued long-term monitoring.

The northern area consists of undeveloped and heavily wooded land. It was into this part of the base that more than 25 million projectiles and explosive charges were launched, and it contains numerous discrete clearings that were targeted during munitions tests. The army estimates that up to 1.5 million fragments of UXO, including 150,000 pounds (68,039 kg) of depleted uranium, may still be present within the Northern Firing Range. Only slightly radioactive, depleted uranium remains after the fissionable isotopes (U-234 and U-235) were removed for use in weapons or reactors. The very dense, depleted uranium was used in projectiles and other weapons to penetrate armor.

The army has removed some depleted uranium and other UXO residues from the northern area but is still developing plans for a complete cleanup. Limited access to this area for hunting and fishing, as well as its use by a local Native American tribe, have been granted, and its use as a recreational and wildlife resource is expected to expand as cleanup activities move forward.

### LAND USE

The DOD is one of the largest landowners, responsible for more than 450 major installations that utilize greater than 25 million acres (10.1 million ha) of land. These bases often have significant effects on the land they occupy. Environmental impacts associated with their respective missions, however, can include damage to local, sensitive, or specialized ecological areas, particularly wetlands. Training areas must provide a realistic experience so that troops and equipment can be tested and acclimated to all types of terrains, including swamps, marshes, permafrost, and coastal areas. The movement of heavy equipment and personnel through such sensitive ecological zones, as well as use of ordnance, often results in significant disruption to habitat. The military now attempts to conserve the land on its bases and host communities. For example, the Pinon Canyon Training Area, Colorado, operates on a two-year rest and rotation schedule for 25 training subunits. No more than 50 percent of the total land is in use at any time. This “rest and rotation” cycle allows environmental recovery of the area between exercises.

These types of land use impacts are usually local and take place well within the confines of most military

bases. The loss of a few tens of acres of wetlands is deemed a reasonable environmental price to pay for a well-trained military force. Critics of these practices maintain that the military disregards the long-term land use. As an example, the island of Vieques just off the coast of Puerto Rico was purchased by the U.S. Navy during World War II and managed as an extension of the Roosevelt Roads Naval Base on the nearby Puerto Rican mainland. For almost 60 years, the eastern tip of the 52-square-mile (135-km<sup>2</sup>) sparsely populated island served as a testing and training ground for bombs and missiles. In the early 1990s, concerned about contamination from the bombing, as well as a high cancer rate among island residents, community leaders on mainland Puerto Rico joined with native Viequians and began to question the need for continued weapons testing on the island. The navy did not respond well, and the questions turned to protests leading to acts of civil disobedience by the late 1990s that interfered with naval operations. Blockades of U.S. Navy warships by local fishing vessels and the regular occupation of bombing ranges by thousands of protestors, some of whom were government officials, union leaders, clergy, actors, and other prominent public people, led to widespread international media coverage.

By 2003, the navy agreed to cease operations on Vieques and turn over its land to the government of Puerto Rico. The bombing ranges were assigned to the U.S. Fish and Wildlife Service for management and decontamination. In 2004, the navy closed Roosevelt Roads. Similar, although much smaller scale land use protests have taken place at Culebra, Puerto Rico, and Kahoolawe, Hawaii.

The U.S. military must also deal with encroachment of private development around its active bases. Residential and commercial development around military facilities can lead to significant restrictions on an installation's mission or even result in its closure. As homes and businesses encroach a base perimeter, civilians can be exposed to the noise, dust, explosive residues, and other environmental consequences related to operations. To ensure that military installations are able to function in a manner consistent with their mission, a number of states and municipalities are addressing encroachment issues. In states with a significant military presence such as Virginia and Texas, legislation has been drafted that requires compatible land use. Some states have created advisory boards to help towns and cities plan development that is supportive of a base's mission.

In other states such as Arizona and California, the region around some military bases has been declared

"areas of critical state concern," and special land use restrictions have been imposed to protect the integrity of the installation's activities. The military also has recognized the dangers of civilian encroachment and usually works with a community when these concerns begin to develop. In some cases, flight paths have been changed to help mitigate noise, and night training exercises are relocated or eliminated. The intent of these actions is not to stop local development, but to organize it in a way that allows the local community to maximize the benefits of hosting a military presence.

See also GROUNDWATER; INORGANIC POLLUTANTS; IN SITU GROUNDWATER REMEDIATION; LAND-FILL; LEAD; ORGANIC POLLUTANTS; SOIL POLLUTION; TCE; VOLATILE ORGANIC COMPOUND.

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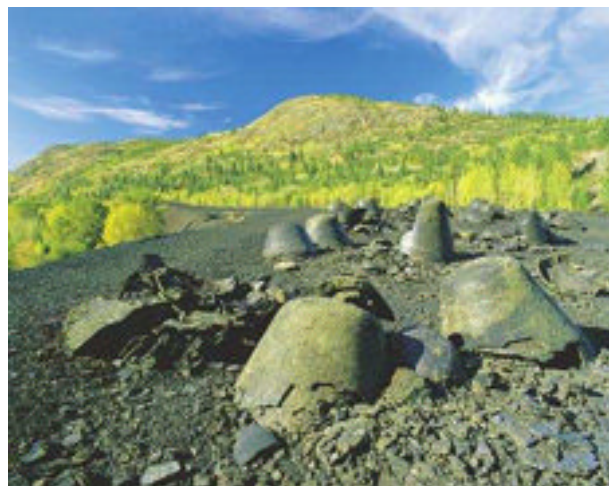
**mining and pollution** Although they are very small and localized sources of pollution, mines and mineral processors are among the most damaging activities to the environment. They can destroy ecosystems and render otherwise productive

areas completely devoid of life. Recovery of these areas can take centuries by natural processes, and, even then, there can still be repercussions. Some examples of the most devastating pollution result from mining, smelting, and processing operations. According to the United States Geological Survey, total domestic mining and waste removal for non-fuel mineral materials production at underground operations amounted to 162 million tons (147 million metric tons) in 2006, and crude ore mined at these underground operations was 158 million tons (144 million metric tons). The balance was ore and waste from development. Total underground mining for industrial minerals amounted to 142 million tons (129 million metric tons), nearly all of which was crude ore. Underground mining for metal ores amounted to only 21 million tons (19 million metric tons), of which 84 percent was crude ore. On a global scale, Stavros Dimas, the European Union commissioner for environment, states that “waste from extractive operations . . . is one of the largest waste streams in the EU.” The vast amount of mining and ore processing conducted in the United States has left an environmental legacy that the Federal Bureau of Land Management has called “substantial.” These wastes include contaminated and acidic water, waste rock and tailings, leaks from chemicals stored at mine sites, and damage to vegetation and wildlife from particulate air pollution (fallout) emitted during mining.

### BASICS OF MINE POLLUTION

The surface of the Earth is constantly modified by physical and chemical processes. The chemical processes primarily involve the dissolution of rocks, soils, and biological debris into surface water and groundwater to form an aqueous solution. Depending upon the dissolved materials, the chemistry of this solution can vary. Where decaying vegetation makes a significant contribution to this solution, as in all temperate regions, it can become acidic. The reason for the acidity is that decaying vegetation produces carbonic acid, which can then drive dissolution of rock and soil surfaces on a large scale.

These and other chemical reactions weather the rock surfaces. This chemical weathering removes the less stable minerals and soils, leaving the more stable minerals behind. For the most part, the more stable minerals, such as quartz, feldspar, and clays are less damaging to the environment and human health. This is because they are less soluble but also because they are so common that life adapted to their presence. Through many millennia of weather-



Slag heap adjacent to a copper smelter in Greenwood, British Columbia, Canada (David Nunuk/Photo Researchers, Inc.)

ing, dangerous chemicals have been progressively removed from the surfaces of the rock exposures and all covering soils.

Mining removes material from underground, where it has not undergone this chemical refining, and places it on the surface, where it is bioavailable. There the abundant highly reactive minerals weather all at once. The dissolution reactions that take place on the fresh surfaces can release hazardous elements into the natural environment at rates that are orders of magnitude greater than those present in nature. This dissolution rate is further enhanced after the rocks have been broken and crushed during mining and processing of the ore. Natural rock surfaces tend to be large and smooth through the years of weathering. The smaller the size of the rock fragments and the more angular their surfaces, the greater the surface area that will be available for chemical reactions. By this process, the crushing of rock can also increase the weathering rate by further orders of magnitude.

Contributing to the pollution from mines more are the toxicity and abundance of the ore mineral itself. The only reason that a mine exists is to remove an economic concentration of a desired mineral. The mineral must be in much higher abundance than is normally present. Although some mined minerals are relatively safe in the environment, most are relatively dangerous. Ore prospects are commonly for their abundance of heavy metals, radioactive elements, asbestos, and sulfur, among other very toxic substances. Even relatively innocuous substances such as salt, lime, and alkalis can be damaging to the environment in high concentrations, especially when ground into a dust.





Water infiltrating mine tailings can produce acid drainage or runoff. Note the bluish color of the copper minerals in the rocks at the foreground. (Will and Deni McIntyre/Photo Researchers, Inc.)

One of the most environmentally damaging products of mining is acid mine drainage (AMD). The waters draining from the mine or percolating through the highly reactive tailings or waste piles can dissolve sulfur and produce sulfuric acid in the soil, surface water, and groundwater. This process is especially prominent in coalfields and sulfide deposits. Plants and animals cannot survive in such acidic conditions, and the area around such mines becomes ecologically damaged or dead. The acidity can further dissolve and strip heavy metals such as lead, copper, and zinc from the mine tailings and surrounding rocks, creating a toxic metal threat as well.

### BASIC TERMINOLOGY

Mineral deposits are those where the target mineral is in high enough concentration within a matrix of other minerals to be mined economically. The target mineral is the *ore*, and it can be metallic, nonmetallic, precious, strategic, or industrial. The minerals that accompany the ore but are not economic are called the gangue, and they must be separated from the ore during processing. To determine whether the concentration of the ore within the mined rock is economic,

it must be *assayed*. This is a chemical analysis to determine the percentage of ore in the rock, which determines its *grade*, a reflection of its *enrichment factor* relative to the average crustal composition. In a mineral deposit, not all of the rocks that are removed are of high enough grade to process. There may be no ore or not enough ore relative to the gangue. These waste rocks are dumped around the mines or where there is space as mine spoils, or *tailings*. In many cases, tailings are carted away and used in construction projects; depending upon the deposit, use of the tailings could be hazardous.

### TYPES OF ECONOMIC DEPOSITS

There are numerous types of economic deposits of minerals. The deposit depends upon the target mineral or material, as do the processes that formed it. Over the years, as the mining and extraction technology advanced, the types of deposits that can be mined economically have expanded significantly. Many current profitable mining operations would never have been considered in the past. Nonetheless, there are several categories of economic deposits that still apply today.

The first classification is based on the type of mineral to be mined. They are either metals or nonmetals. Metals can be abundant, such as iron, aluminum, and magnesium; scarce, such as zinc, chromium, and tin; or strategic, such as platinum, palladium, and rhodium, among others. Individual metals may switch categories with time depending on need. Nonmetal mineral ores may be used for chemical production such as salt (halite), sulfur, and borax; for fertilizers such as calcite (lime), apatite (phosphate), and sylvite; for building materials such as gypsum (plaster), clay, sand and gravel, and crushed rock; for jewelry such as diamonds, corundum (ruby and sapphire), and beryl (emeralds); and for ceramics and abrasives, among others.

The geologic classification of ore deposits is based on the processes that formed them and include igneous, sedimentary, weathering, and metamorphic.

### Igneous Processes

Igneous and sedimentary processes are the most common types. Igneous processes form most metallic and precious mineral deposits but may also form nonmetallic and industrial mineral deposits as well. The deposits from igneous processes include pegmatites, crystal settling, disseminated, hydrothermal, and volcanogenic.

#### Pegmatites

Pegmatites are very coarse-grained igneous rocks that cool underground directly from magma. They are mainly light-colored rocks that form by filling planar cracks and as such are typically tabular in shape. Pegmatites are the last bodies to form in igneous processes and, as a result, contain high amounts of water and other incompatible elements that are not common to igneous rocks. The water subdues nucleation of crystals, allowing the few that form to grow very large. One pegmatite from the midwestern United States had crystals up to 40 feet (12 m) long. The abundance of incompatible elements encourages the production of uncommon minerals, such as spodumene, a lithium-rich mineral, and tourmaline, a boron-rich mineral, among others. Pegmatites may also be mined for beryl (including emeralds), uranium minerals, garnet, mica, and feldspar, among others. Large mined pegmatite deposits occur in California, Maine, and Brazil.

#### Crystal Settling

The intrusion of mantle-derived mafic magma into the crust may produce a plutonic igneous body called a layered mafic intrusion. These bodies appear to intrude and cool slowly under quiet conditions of little additional magma or deformation. The crystalliz-

ing minerals can settle unimpeded through the liquid magma to the bottom of the magma chamber, where they can accumulate into an economic deposit. The most common ores to form by this process are platinum, chromite, nickel, and magnetite (iron). Large mined examples occur in Pennsylvania, Maryland, California, Montana, and South Africa.

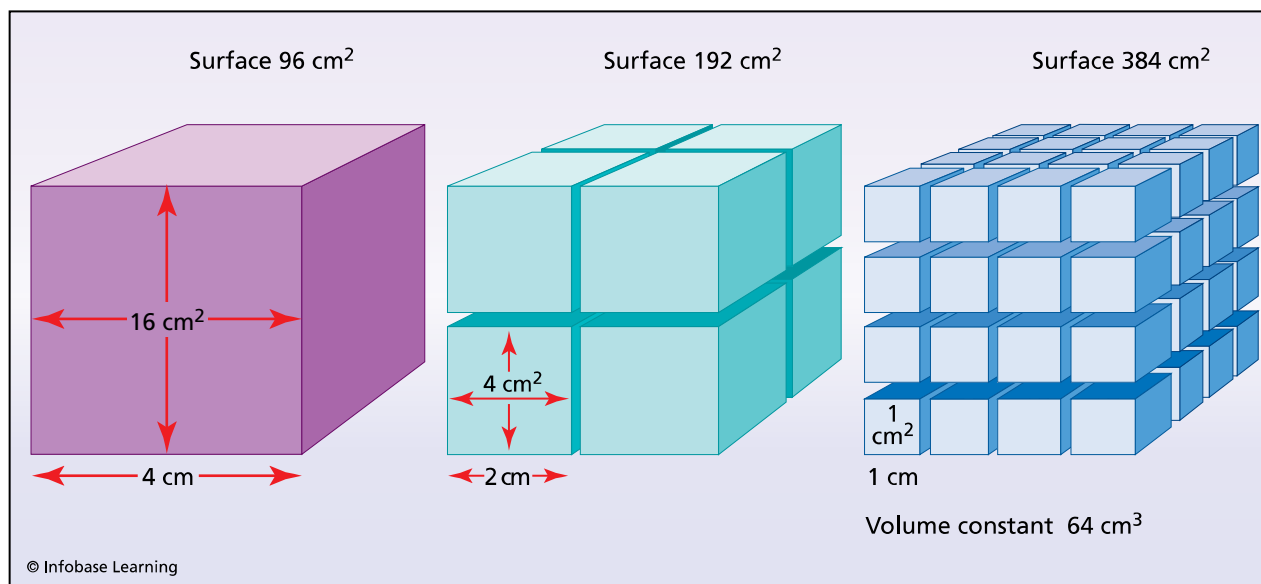
#### Disseminated

Disseminated ores occur scattered in very small cracks and in spaces between mineral grains at the top of large igneous intrusions. These ores occur in low concentrations but over large volumes of rock. Sometimes referred to as porphyry deposits, disseminated ores can produce some of the largest accumulations in the world but spread out over so much gangue material that the cost of extraction may be excessive. Nonetheless, the Bigham Mine in Utah is a porphyry copper deposit that is the largest source of copper in the world. Its estimated value is \$6 billion.

Diamonds also occur as a disseminated ore, but their mode of formation is much different. They are formed deep in the Earth in the mantle (90–120 miles [150–200 km] deep), where pressures are extreme. They form in a gas-charged fluid-liquid-rock mixture that is gravitationally unstable. If fractures open above this mixture, they shoot explosively through the crust at speeds up to mach 2 and emplace in funnel-shaped pipes at or near the surface surrounded by crushed rock. The deposit is called a kimberlite, named after the classic example in Kimberly, South Africa, and it is the only source of diamonds. A kimberlite is the only way diamonds could make it to the surface because if they were raised up more slowly, they would convert back to graphite.

#### Hydrothermal

As the name implies, hydrothermal deposits are produced by hot aqueous fluids that transport the ore into a chemically favorable area. As a magma body cools and crystallizes, it releases massive amounts of very hot water. This water can dissolve and carry large amounts of metals and other ions but only as long as they are hot, under pressure, and in a certain pH range. As soon as they encounter other conditions, they precipitate the dissolved chemicals, primarily into cracks, faults, and pores, or they may even replace certain rocks by simultaneously dissolving them and precipitating the chemicals in their place. The replacement of layers of rock or sediment by hydrothermal fluids produces *stratabound* deposits that look like layering. The ore deposited in wide cracks forms tabular shaped *veins* that miners refer



**Diagram showing the enormous increase in total surface area of an object by breaking it into smaller pieces. Chemical reactions that release pollutants to the environment occur on the surface of mined rock.**

to as lodes. The most famous hydrothermal deposits form the Mother Lode gold-quartz ore in California, but many rich deposits of lead, zinc, and magnetite (iron) in many areas form this way.

### Volcanogenic

When volcanic activity occurs under the sea, chimneys, called black smokers, that constantly spew gas, fluid, and particles, are a common occurrence. Either these volcanic emissions deposit economic minerals directly on the seafloor, or the ocean water becomes saturated with metals and other ions, and they precipitate them onto the seafloor. The result is an interlayered sequence of volcanic rocks, deep sea sediments, and massive sulfides and base metals. The most common metal is copper, but zinc, iron, nickel, and magnesium are also possible. The best examples of volcanogenic deposits are the massive copper deposits in the island of Cyprus (whose name means “copper”).

### Sedimentary Processes

Sedimentary deposits are probably the most important of the mined economic materials. It used to be that all metals were from igneous deposits, but they are increasingly from sedimentary deposits as technology has progressed. There are also many minable deposits that are only from sedimentary rocks. There are two processes by which sediments are formed: They are transported and deposited either as particles or as dissolved elements and compounds.

### Precipitants

Dissolved compounds can be precipitated in shallow marine conditions and deep marine conditions. The processes for precipitation are supersaturation of water by dissolution of rocks and minerals enhanced by evaporation of the water from the solution and biologically enhanced precipitation. Some precipitation occurs in the open ocean, but, by far, most occurs in restricted basins with limited circulation. Even in open oceans, precipitation generally occurs in the deep oceans at the seafloor, where circulation is limited. The most common deposits are of rock salt, carbonates, and agates, mostly in warm areas such as the Gulf of Mexico. Manganese nodules are also deposited on the deep ocean floor. Shallow marine deposits include phosphates that are biologically enhanced and, in the distant past, banded iron formations (BIFs). These massive deposits occur in the upper Midwest and Canada and have provided most of the iron used in the United States.

### Evaporites

Even though evaporites form in a similar manner to precipitants by supersaturation of the water, in these deposits, evaporation from the Sun is the overwhelming process. Evaporites can form under terrestrial or restricted shallow marine conditions. In terrestrial conditions, evaporites can form in seasonal lakes and ponds or shallow seas that are cut off from the open ocean. Through evaporation, the waters supersaturate with ions and precipitate the

minerals, and some may be formed by chemical reactions after precipitation. Deposits may include gypsum (plaster), carbonates (lime), borax, and various alkali salts (including halite). There are large evaporate deposits in the Michigan basin and in the Basin and Range Province of the United States. The same minerals are found in shallow marine deposits, but they are typically in greater volume.

### Coal

Although coal would be better included in a discussion on energy, it is included here because it is mined. Today, there is more mining of coal in the world than all of the other types combined. Coal was mainly formed during the Carboniferous period of Earth history about 300–250 million years ago but also later in several areas. Coal forms when excess dead vegetation deposits in shallow water such as in swamps and other wetlands. With time, it is buried under sediments and compressed and heated. It first turns into peat and then into coal. Coal advances

through ranks from lignite to bituminous coal to anthracite with age and burial. The Appalachian Mountains and plateau (Allegheny) to the west produce anthracite, and the Rocky Mountains produce bituminous coal.

### Placer Deposits

Ores can be eroded from surface exposures of rock and carried as particles in surface water. Particles of many metallic ores are denser than the rest of the sediments carried by streams. Any section where stream flow slows, sediment particles are deposited in sand and gravel bars. The ore settles first by virtue of the density, and a higher percentage settles out than the other particle types. This process concentrates the ore particles into a small area called a placer deposit. The most commonly mined placer deposits are gold, platinum, and silver because they are dense. Diamonds may also form placer deposits, but they do not concentrate as the metallic ores do because diamonds are not so dense.

## OCCURRENCE OF METALLIC MINERALS

Metal	Principal Ores	Geological Occurrences
Aluminum	Bauxite	From residual weathering
Chromium	Chromite	Settling in magma; differentiation during cooling
Copper	Chalcopyrite, bornite, chalcocite	Hydrothermal deposits; contact metamorphism
Gold	Native gold	Hydrothermal deposits; placers
Iron	Hematite, magnetite, limonite	Banded formations; magmatic segregation; hydrothermal
Lead	Galena	Hydrothermal deposits
Magnesium	Magnesite, dolomite	Hydrothermal deposits
Manganese	Pyrolusite	From residual weathering
Mercury	Cinnabar	Hydrothermal deposits
Molybdenum	Molybdenite	Hydrothermal deposits
Nickel	Pentlandite	Settling in magma
Platinum	Native platinum	Settling in magma; placers
Silver	Native silver, argentite	Hydrothermal deposits; enrichment by weathering
Tin	Cassiterite	Hydrothermal deposits; placers
Titanium	Ilmenite, rutile	Settling in magma; placers
Tungsten	Wolframite, scheelite	Pegmatites; contact metamorphism; placers
Uranium	Uraninite (pitchblende)	Pegmatites; sedimentary deposits
Zinc	Sphalerite	Hydrothermal deposits



### **Sand and Gravel**

Particles of sediment that are not economic in their own right can concentrate to form sand and gravel deposits, which are economic. Sand and gravel are concentrated in several sedimentary processes, most notably in streams and in glacial outwash deposits. As such, they are more common in the northern United States than in the South. Sand and gravel are not particularly rare, but they are used in massive amounts in construction projects involving poured concrete and asphalt including those in all cities. The problem is that transporting all of the necessary sand and gravel great distances from the source to the cities is very expensive. Deposits closer to cities are worth a lot of money.

### **Clay**

Although not readily apparent, clay is a high-volume industrial mineral. It is used in cat litter, for the slick coating on paper, in china and other ceramics, and in bricks. Clay is deposited in great volumes on the ocean floor, but it is not available for mining. Shallow water deposits are less common because they require areas with very low energy conditions with no input of sand or gravel. Clays are mostly taken from lagoons and bays in marine settings, lake deposits and especially glacial lakes, and some floodplain deposits around rivers. Clay deposits in Georgia are called “white gold” because they are worth so much money, but clay deposits are not uncommon.

### **Weathering Processes**

There are certain weathering processes that remove minerals by chemically dissolving them and transporting them away. This redistribution of elements and compounds forms the basis for the formation of economic deposits through weathering. Though not nearly as important as igneous and sedimentary processes, weathering processes, nonetheless, form some economically important deposits.

### **Laterites**

The deep weathering of soils in tropical climates with high precipitation strips away many of the unstable and even relatively stable minerals. The warm temperatures and abundant acidic waters enhance chemical alteration and dissolution. The speed at which removal takes place is a measure of chemical mobility. Immobile elements and compounds are those that are left behind. Under these conditions, none is more immobile than aluminum, which accumulates in lateritic soils, forming bauxite. Bauxite is aluminum ore that is mined in the Tropics.

### **Secondary Enrichment**

The fluids that dissolve compounds during weathering can redeposit it if conditions are favorable. In many cases, oxidized elements are mobile, and reduced elements are immobile. Fluids carrying dissolved ions can percolate through sediments and soils with minimal exchange of ions until they encounter a reducing environment. Such environments might be limestone- or organic-rich deposits such as shale, coal, or biomass. The chemical reactions, in this case, can precipitate the dissolved ions upon contact. Certain bacteria can enhance this process, as well. There are many examples of such interactions such as the petrified forest of Arizona and sulfide deposits in many swamps. The most economic example is that of uranium, which has been found to deposit on buried logs and other vegetation and in clays, among others.

### **Metamorphic Processes**

Metamorphic processes are the least important for the generation of ore. There are many economic deposits in metamorphic rocks, but the majority of them were emplaced while the rocks were igneous or sedimentary. Hydrothermal activity can occur in metamorphism, as well as in igneous processes, and produce similar deposits. There are a few processes that are unique to metamorphism that tend to produce useful minerals and possibly even some metal deposits.

### **Contact Metamorphism**

If a magma body intrudes crustal rocks, it metamorphoses the rocks around it. This metamorphism imposes no change in pressure but radically changes the temperature and the fluids. The volume of rock affected by the body is called the aureole and undergoes contact metamorphism. Economic deposits of minerals can be produced in the aureole depending upon the composition of the rock that was intruded. The best rock to intrude for deposits is limestone. Not only can minerals with useful elements such as tungsten and molybdenum form, but minerals with useful properties may also form. For example, wolastonite is a bladed mineral that is used as filler in car body panels. Shales may also form useful minerals through contact metamorphism such as emery deposits (corundum), which are used as excellent abrasives.

## **TYPES OF MINING OPERATIONS**

There are basically two types of mining operations, surface and underground. There are several types of each of these depending upon the type of matrix around the ore. The choice of the type of mining employed depends upon numerous other factors

### OCCURRENCES AND USES OF NONMETALLIC MINERALS

Mineral	Uses	Geological Occurrences
Apatite	Phosphorus fertilizers	Sedimentary deposits
Asbestos (chrysotile)	Incombustible fibers	Metamorphic alteration
Calcite	Aggregate; steelmaking; soil conditioning; chemicals; cement; building stone	Sedimentary deposits
Clay minerals (kaolinite)	Ceramics; china	Residual weathering
Corundum	Gemstones; abrasives	Metamorphic deposits
Diamond	Gemstones; abrasives	Kimberlites; placers
Fluorite	Steelmaking; aluminum refining; glass; chemicals	Hydrothermal deposits
Garnet	Abrasives; gemstones	Metamorphic deposits
Graphite	Pencil lead; lubricant; refractories	Metamorphic deposits
Gypsum	Plaster	Evaporite deposits;
Halite	Table salt; chemicals; ice control	Evaporite deposits; salt domes
Muscovite	Insulator in electrical devices	Pegmatites
Quartz	Glass	Hydrothermal; sedimentary deposits
Sulfur	Chemicals; fertilizer manufacture	Sedimentary deposits; hydrothermal deposits
Sylvite	Fertilizers	Evaporite deposits
Talc	Paints; cosmetics	Metamorphic deposits

besides the type of ore and gangue. Factors include shape and depth of the ore body, population density around the mined area, grade of the ore, regulations on mining in the area, available technology, and the amount and depth of surface water and groundwater in the area. Most mining is underground unless the ore body is shallow, economic, and extensive and all of the other listed limiting factors are minimized.

#### Underground Mines

Underground mining techniques must be employed if the ore body extends to a significant depth. Vertical and subvertical ore bodies must also be accessed by an underground mine, though the top of the body may be surfaced mined as well. In most cases, however, a tunnel must be cut to the ore body before large-scale mining can begin.

The tunnels to access the ore body are most commonly declines, shafts, or adits. Declines are usually inclined spiral tunnels that circle either the flank of the deposit or the deposit itself. They begin at the surface or in a surface mine with a box-cut portal

to the surface and may be lined with a galvanized steel culvert for safety purposes. Shafts are vertical tunnels adjacent to the ore body that are serviced by using elevators. Shafts are preferred for ore bodies where haulage to the surface using trucks is not economical. Adits are horizontal tunnels into the side of a hill or mountain that are used for horizontal or near-horizontal ore bodies.

Once the access tunnels reach the ore body, there are several methods of mining it. Room and pillar mining consists of intersecting cavities, or rooms, with pillars of rock that hold up the roof. The pillars are later mined when that part of the mine is closing. Longwall mining is accomplished using a machine called a continuous miner that cuts layers of coal or minerals from the walls. There are several tactics in moving through the ore body with regard to the waste rock generated. In stope and retreat mining, rocks are extracted from the stopes (rooms) without filling the open voids. This method allows the wall rocks to cave in to the void after the ore has been removed. The stope is then sealed. In contrast, in stope and fill, after

the ore is removed, the open stope is backfilled with a cement and rock mixture, a cement and sand mixture, or a cement and tailings mixture. Cut and fill mining is similar to stope and fill but with a short hole in narrow ore zones. An access ramp is cut into the bottom of the ore zone, and a drift is driven through the ore. The drift is then backfilled to the access ramp. Drift and fill is similar to cut and fill, but it is used in ore bodies that are wider than the drifting method allows. Block caving is used with large ore bodies of low-grade, friable ore. Blasted ore is removed underneath the friable ore until an area of unsupported ore begins to fracture and cave in on its own.

### Hard-Rock Mining

Hard-rock mining is underground mining into solid or crystalline bedrock. An opening called an adit is excavated at the surface. Tunnels extending from the adit and into the rock are drilled out and blasted with dynamite. The tunnels, called shafts, are cut vertically downward into the rock until they encounter the ore body. Numerous shafts are cut for miners to use to go into and out of the mine, for mine machinery, and for ventilation. The tunnels in hard-rock mines generally use room-and-pillar techniques. Ores in hard-rock mining contain metals such as gold, copper, zinc, nickel, and lead or gems such as diamonds, emeralds, and rubies.

There are several ways to access and mine the ore in underground mining. The opening in a *shaft mine* is made by opening a vertical tunnel downward to the elevation of the coal seam. Short tunnels to the ore are dug from the main shaft. Mining is conducted by using typically either longwall mining or room-and-pillar mining with continuous mining equipment. The ore is dynamited, broken into chunks, and taken to the top to be loaded onto trucks. With *slope mining*, the ore layer is located very deep and is horizontal or subhorizontal. It is called a slope mine because the access shafts are slanted and sloping. This kind of mining is preferred if there are difficulties drilling shafts straight down. Slope mines are usually relatively shallow in the earth.

Drift mines are a form of underground mining that is done when the ore is on the side of a hill or mountain and accessible by using horizontal tunnels. The tunnels that are horizontal are called drifts. If possible, the drift is dug a little lower than the ore body. This makes it easier to take the materials out because gravity helps move them downhill.

### Borehole Mining

With borehole mining, a shaft or tunnel is drilled deep enough into the ground to reach the ore body. A long tubelike tool is lowered into the hole. The tube has places for water to be forced out of holes or ports and other places where the water can be pushed back up the tube. The water is forced down this tube, and the stream breaks up the dirt and rock. The water combines with the dirt, rock, and minerals to make a combination called a slurry. The slurry is pumped back up to the surface, where it is put into a storage tank. The water is drained and the ore is taken out of it.

### Surface Mines

Surface mining techniques must be used in some cases and can be used in others. The most common surface mines are strip mines. In this case, all of the rock above the ore (overburden) is removed by using heavy machinery and dumped.

### Strip Mining

In strip mining, a very shallow ore seam is first exposed by removing all of the overlying soil and rock, otherwise known as the overburden. The ore is then excavated and removed from the surface. Strip mining is most commonly used to mine coal or tar sand. Strip mining is only practical when the ore body is near the surface. This type of mining uses some of the largest machines on Earth, including bucket-wheel excavators that can move as much as 412,000 cubic feet (12,000 m<sup>3</sup>) of earth per hour.

There are two types of strip mining, area stripping and contour stripping. The more common method is *area stripping*, which is used in relatively flat areas, to extract ores that cover a large area. As each strip is excavated and removed, the overburden is backfilled into the excavation from the previous strip. *Contour stripping* involves removing the overburden above the ore body near its outcrop in a hilly or mountainous terrain, if the outcrop of the ore follows the contour of the land. Contour stripping commonly leaves behind terraces in mountainsides and hillsides.

### Open-pit mining

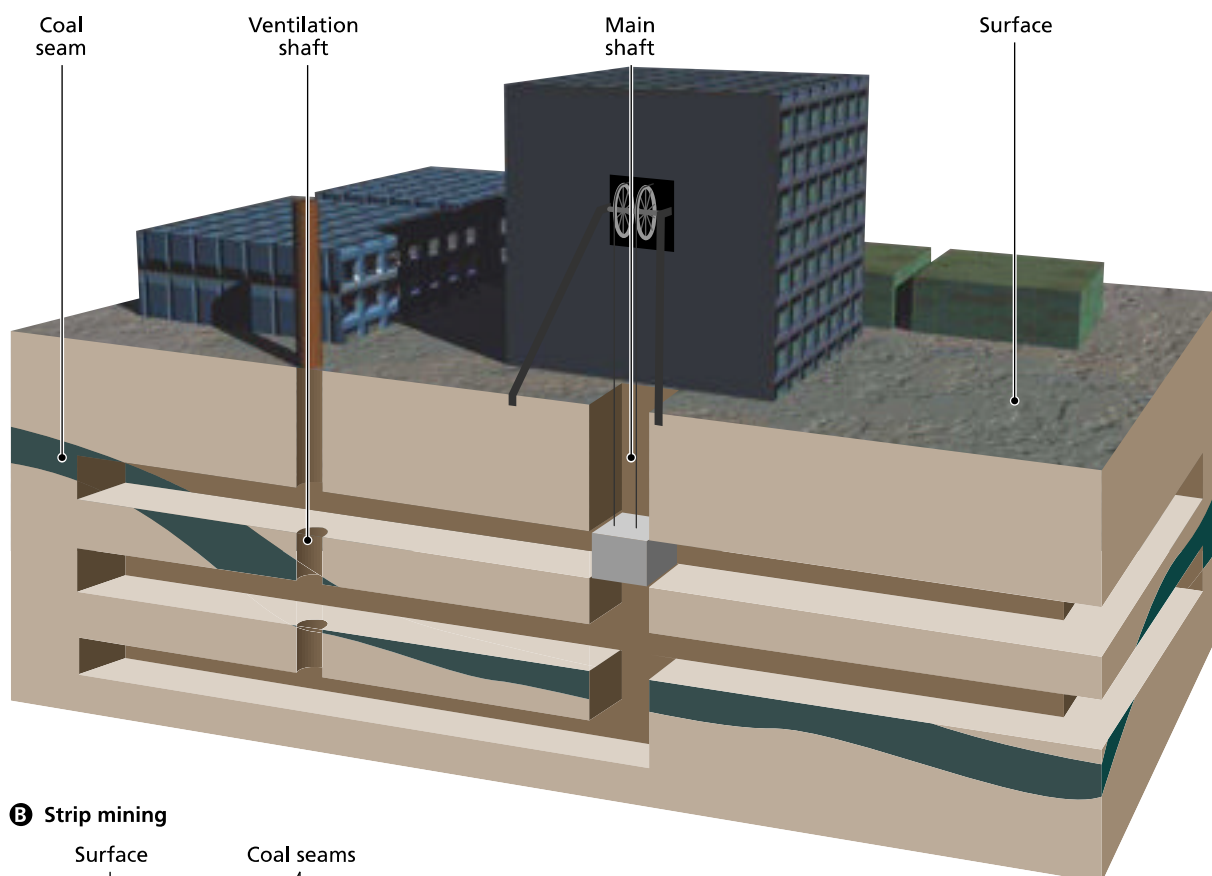
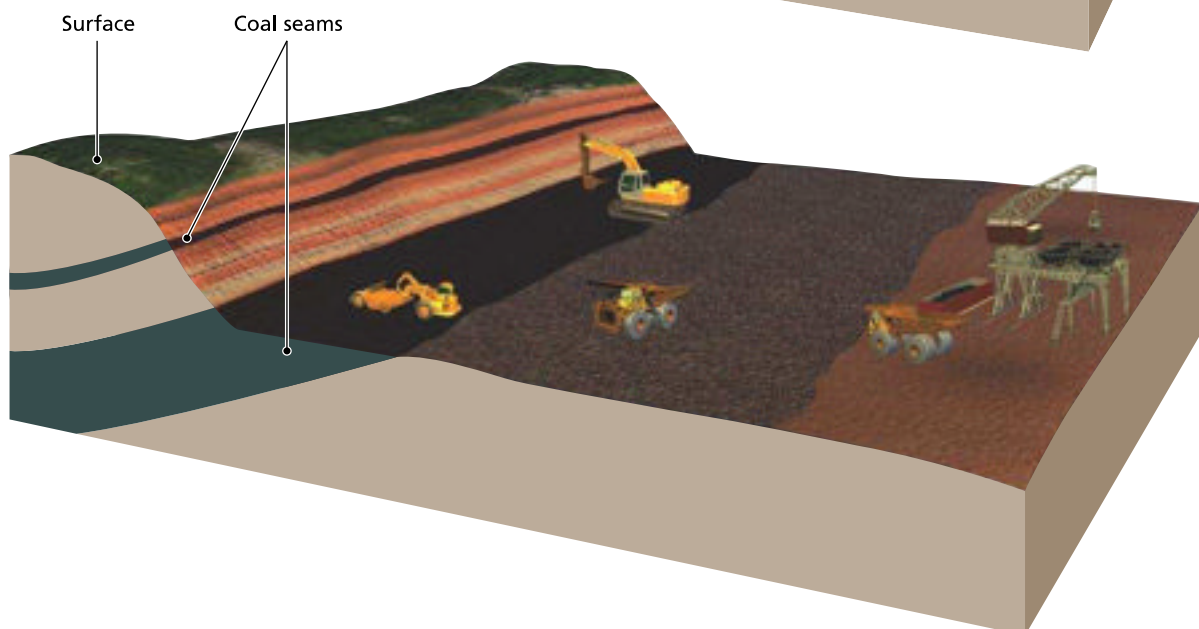
Also known as opencast, open-cut, and strip mining, open-pit mining is a method of extracting ore by removal from an open pit or borrow. Open-cut mines are excavated on benches equivalent to vertical levels of the hole.

(*opposite page*) Block diagrams showing the two major types of mining: underground (subsurface) and strip mining. Underground mining is for deep-seated ore and leaves a maze of tunnels underground and piles of waste rock on the surface. Strip mining is for shallow ore and removes the entire surface.

**Mountaintop removal (MTR) mining**

A relatively new form of mining for coal, in which there is massive restructuring of the surface in order to reach the coal seam, which may be as deep as

1,000 feet (308 m), is mountaintop removal mining. It is used where the outcrop of the coal seam completely encircles a mountain. All of the rock and soil above the coal seam are removed and dumped

**A Underground (subsurface) mining****B Strip mining**



into adjacent hollows and ravines and any other low spots. Mountaintop removal replaces mountains with relatively level surfaces.

### Highwall Mining

Another form of surface coal mining, highwall mining is a variant of surface auger mining. In highwall mining, the coal seam is continuously excavated by using a piece of hydraulic equipment called a push-beam transfer mechanism (PTM) that cuts into and strips out the ore.

### Dredging

Dredging is a method that is commonly used to excavate underwater mineral and ore deposits, and especially placer deposits. Dredging is usually used to clear or enlarge channels for boats in major waterways, but it can also be used to recover underwater ores in a relatively cheap and efficient manner. Depending upon the deposit, dredging can be done by using large channel dredging equipment or a small floating vacuum.

### Gold Mining

Gold mining is considered as a special case because there is a chemical method that was used in many areas. In placer deposits, much of the gold is not in pure form but instead occurs in particles with gangue minerals. In order to remove the gold from the waste rock, mercury can be mixed with the particles; the mixture then strips out the gold to form an *amalgam* that can be easily separated. A chemical process to remove the mercury is applied later. This method was heavily used in the second half of the 19th century in California, where 0.75 pound (0.34 kg) of mercury was introduced to the environment for every 1,000 pounds (455 kg) of ore processed. In all, about 12 million pounds (5.5 million kg) of mercury was released into the surface waters surrounding the famous Comstock Lode of Nevada during gold mining operations. This caused heavy mercury pollution (on average, 10–100 times background levels) that is still causing problems today. Replacing the mercury amalgam method was cyanide leaching, which began around 1900. This method can be used at the mine or later in processing.

After mercury processing was abandoned in the United States, in order to remove the gold from the gangue minerals and metals, a process called cyanide leaching was discovered in 1887. The ore was soaked in cyanide, which dissolved the gold into solution. Zinc shavings were then added to the solution. The zinc shavings bonded with the gold, and the cyanide solution could be drained away. The shavings were then heated and the zinc vaporized, leaving the gold

as a residue. The method is basically the same today, but miners now use a process called heap leaching, in which the cyanide solution is drained through a pile, or heap, of ore and collected below. The problem, of course, is that cyanide is a poison deadly to both humans and wildlife. Any release has dire consequences.

## EXAMPLES OF POLLUTION FROM MINES

The Panguna Mine in Bougainville, Papua New Guinea, was one of the most polluted mining areas in the world until it closed in 1989. The aggressive mining operation extracted copper sulfide ore for processing and dumped an average of 600 tons (545 metric tons) of tailings into the Kewerong River per year. The waste rock covered seven square miles (1,800 ha) of the river system, including the 2.7-square-mile (700-ha) delta. Infiltration and dissolution of the sulfur-rich tailings by precipitation and surface water resulted in acidic surface water and groundwater. The low pH killed all of the aquatic life in the surface waters and infuriated the local residents. An article in the commercial mining trade press (*Trading Markets*) clearly characterized this flagrant environmental destruction as one of the major causes of an ensuing civil war: “The mine closed in 1989 as the Papua New Guinea island descended into secessionist conflict spurred by land-owner issues and the environmental damage the mine was causing.”

The island of Nauru in the South Pacific had a large phosphate prospect that was first mined in 1906 by Germans. Through most of its history, it was part of Australia, which destroyed the land in an attempt to remove all of the phosphate. The residents of Nauru won a major legal battle against Australia over the environmental damage. Most of the large-scale mining ended in 2008, but more than 80 percent of the eight square-mile (2,100-ha) island has been damaged or destroyed by the mining.

The Summitville Mine complex in the San Juan Mountains of Colorado has a twofold environmental problem. It is a gold mining complex, and there are other heavy metals associated with the ore. Gold was first discovered at Summitville, in 1870, and there was significant gold production from underground workings prior to 1900. In 1903, the Reynolds adit was built to drain the mine and serve as an ore haulage tunnel to renew production, which occurred sporadically through the 1950s. Production basically ended afterward, but as a result of new advances in separation techniques using cyanide heaps, in 1984, open-pit mining of gold ore from waste rocks surrounding the old underground work-

ings was renewed. The new techniques and rising price of gold made it economic to process ores where gold concentrations had been previously too low. The environmental problems of the mine surfaced in 1992 and 1993, when the cyanide solutions began leaking into the surface water and groundwater systems of the area. A full investigation of the area released in 1995 found that the cyanide was a minor problem compared with the acid-generated heavy metal contamination, which poisoned 17 miles (27 km) of the Alamosa River. The U.S. Environmental Protection Agency placed the site on the National Priorities List in 1994, even before the report was released. Cleanup of the site is costing about \$120 million.

Environmental problems with mines are not restricted to exotic or isolated areas. The U.S. Environmental Protection Agency recently concluded that “over 95% [of the Mid-Atlantic states acid mine drainage problem] is located in western Pennsylvania, . . . West Virginia . . . southeastern Virginia . . . and far western Maryland.” There is even a case of acid mine drainage in Garrison, New York, about 35 miles (56 km) north of New York City. The deposit was first mined for copper, but the main ore quickly became the massive sulfide deposit. It was mined during the late 19th century, and the ore was loaded onto barges in the Hudson River 0.5 mile (0.8 km) downhill and taken to Staten Island for processing into sulfuric acid. The mine was abandoned by 1900, but the exposed sulfide-rich tailings have been weathering since. Surface water and groundwater that infiltrate the tailings piles and dissolve the sulfides, producing acid mine drainage with pH as low as 1.78. There is no vegetation growing on the tailings and mine soils. The acid strips out heavy metals from the tailings and contaminates the groundwater and surface water in the area.

### TRANSPORTATION OF ORE

Once removed from the mine, crushed, and separated, most metallic ore must be transported to a furnace or foundry for processing. The most common method of long-distance transportation for bulk ore is by rail or by barge if the mine is on a navigable river. Local transportation is done by truck, depending upon the product.

The main issue with pollution from transportation of ore results from accidents and incidental loss from material blown off the transportation system. Railroad lines that are used to transport coal are invariably covered in a fine coating of black coal soot. The extent of the loss depends upon the speed of the train, condition of the rails and train, and strength of prevailing winds. The pollution from this

source is not a major concern in almost all cases. Transportation loss and windblown loss of phosphate, however, can produce problems. Rail lines from phosphate pits in Florida cross Georgia and Alabama. Significant amounts of phosphate have blown off the open cars for more than 50 years. Vegetation around the lines is lush from the fertilizer effect of the phosphate, which also enhances eutrophication in nearby rivers and ponds. Phosphate minerals are also enriched in uranium and radium. The soils around the current and closed rail lines contain high levels of radon, which can affect the indoor air quality in nearby homes. Windblown asbestos and lead, among others, from train cars and trucks can also lead to public health concerns.

### BASICS OF SMELTING AND REFINING

Some ore is used as is or with minor processing such as separation and crushing. Most evaporites and minerals used for their physical properties such as asbestos, garnet, and other abrasives and wollastonite are in this category. Other ores must be chemically altered before they can be used. Most metals are contained in compounds and must be chemically separated from other elements before they can be used. Only metals in their native form such as gold, silver, and some copper and iron do not require appreciable processing. There are several basic steps in the smelting and refining process.

The first chemical processing of ore is smelting in a furnace. Three ingredients are needed for this: ore, fuel, and flux. The location of furnaces is usually convenient to the source of fuel, which has been coal for at least a century. Before that, charcoal was also commonly used. The fuel is burned in a furnace with air pumped in to increase the temperature. The ore is then dumped in with a flux to drive a chemical reaction to remove the unwanted elements and compounds from the ore in this molten state.

To make iron, the ore is either magnetite or hematite, both of which are iron oxides with varying valence states. To make pure iron, the oxygen must be removed and the ore reduced. The flux for this reaction has been limestone since ancient times. The limestone is first crushed and baked (calcined) before being added to the furnace. Once it is in the furnace, a reaction takes place:



The volatile compounds  $\text{CO}_2$ ,  $\text{O}_2$ ,  $\text{H}_2\text{O}$  boil off to the atmosphere, the molten iron goes to the bottom of the furnace, and the slag, which is a compound of leftover elements, rises to the top, where it is

skimmed off and disposed of. In historical times, the liquid iron would have been decanted off to a casting room with a sand floor. It flowed along a main channel and off into ingot-shaped hollows, where it cooled and hardened. The shape looked like piglets (ingots) suckling on a sow (main channel), and, as a result, it was called pig iron. This iron has a lot of impurities and must be refined before it can be used for anything useful. In ancient times, it was beaten into an object, but later it went to a steel mill. Iron production, although principally the same, is far more sophisticated, producing high-quality steel in a single process.

Although the mining and infrastructure can be damaging, the by-products of iron production are relatively benign to the environment and public health. The production of other metals, however, can be quite damaging. One of the most damaging ores is sulfide. Much of the lead, copper, and zinc ore occurs in the form of sulfides. The sulfur must be removed from the metal in smelters to produce economic metals. For most of history, the sulfur compounds were released to the atmosphere from smokestacks and settled to the ground around the smelter or contributed to acid precipitation somewhere else. In some historical smelters, the sulfur was recovered and sold, and, today, filters are required by law to prevent the release of sulfur. In the vast majority of the smelters, the sulfurous fallout made the soil and surface water so acidic that it killed all life in a significant area around the plant.

### EXAMPLES OF POLLUTION FROM SMELTING AND REFINING

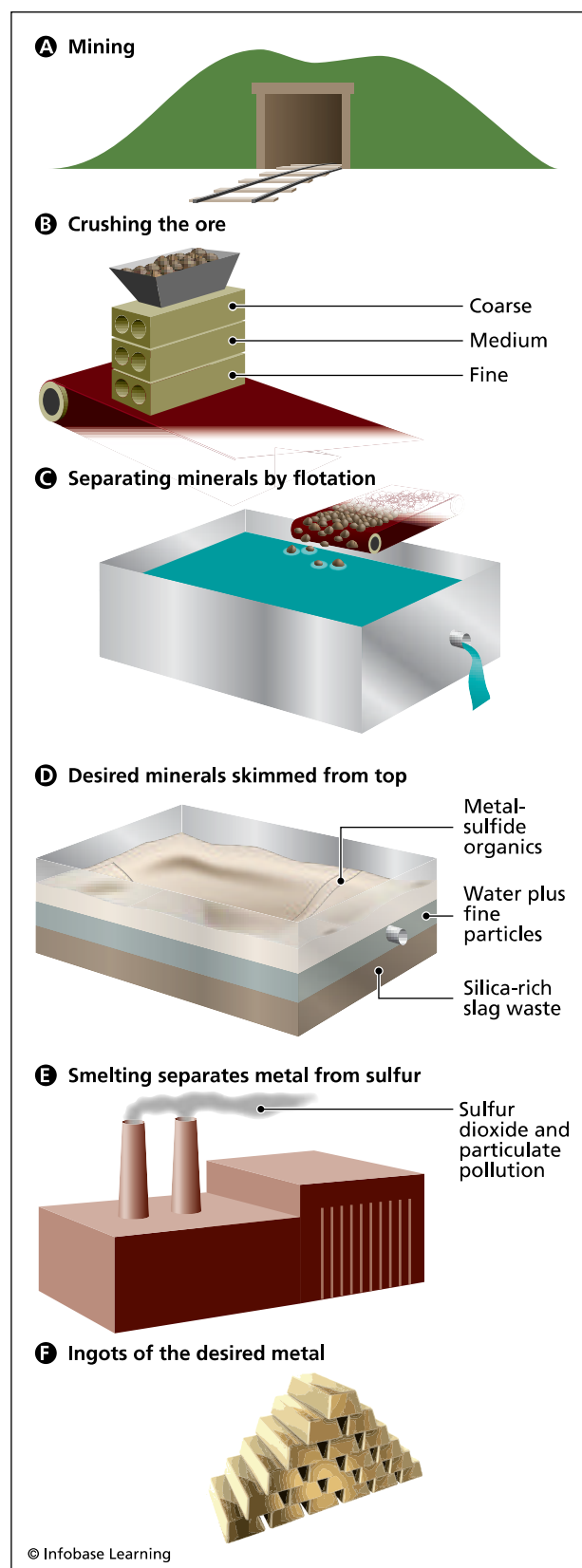
There are numerous cases of profound pollution from smelter operations. Perhaps the most impressive of these is in Sudbury, Ontario, Canada, where nickel and copper sulfides have been smelted adjacent to the mine complex. As the result of sulfuric acid fallout, a vegetation dead zone developed around the smelter complex and reached 40 square miles (10,400 ha) in size. Fish and other animal populations were completely eliminated within a 40-mile (65-km) radius of the smelter. The government undertook an aggressive  $\text{SO}_2$  reduction program including the building of the world's tallest smokestack, and the area has recovered over the past three to four decades.

Another example of profound pollution caused by smelting and refining operations is Norilsk Mining and Smelter in Norilsk, Siberia, Russia. The mines yield nickel, copper, and other metallic elements to form concentrated deposits of sulfides. Estimated reserves for the deposit are almost 2 billion tons (1.8 billion metric tons), which are removed from

underground mines that extend more than 3,900 feet (1,200 m) belowground. These ore deposits were known for many years, but mining operations did not begin until around 1935 and continue today. The environmental effects of smelting the ore in the facilities adjacent to the mining operation are severe. An area with a roughly 25-mile (40-km) radius around Norilsk is ecologically dead, all of the trees and other vegetation killed by acid rain. The landscape is scarred with open pits and piles of waste rock and debris. In some places, the upper few feet of soil is so heavily contaminated by fallout of nickel and copper that it is economic to mine. Almost 15 percent of all the industrial pollution in Russia is produced by the Norilsk plant, as its main Nadezhda Metallurgical facility has emitted more than 2 million tons (1.8 million metric tons) of sulfur dioxide into the atmosphere every year since 1950. Wastewater used in ore processing is discharged without treatment into surface water bodies and has contaminated more than 60 miles (100 km) of streams and rivers. It is estimated that annual discharge of unprocessed industrial sewage from Norilsk smelters and mines into the sensitive Siberian ecology is more than 500 million gallons (1,893 million L).

There are also profoundly contaminated sites in the United States. The Bunker Hill Mine Superfund Site of Shoshone County, Idaho, is a prime example. The first mines that extracted lead and silver ores opened in Shoshone County in 1889. At peak production, the mine area covered 6,200 acres (2,509 ha), was more than one mile (1.6 km) deep, and had nearly 125 miles (201.2 km) of underground roads, adits, and shafts. Much of the smelting and refining was done on the premises. During the 1970s, the Bunker Hill smelter was the second largest in the United States, producing more than 20 percent of the country's lead and zinc and nearly one-fifth of the processed lead in the world. Between 1965 and 1981, the smelter released more than 6 million pounds (2.7 million kg) of lead into the atmosphere. During processing of the ore, large amounts of lead dust were emitted but quickly settled around the mill, where they contaminated the soil, washed into surface water, and leached into underlying groundwater. The lead in this airborne dust represented a serious threat to the health of workers and local residents. The Bunker Hill Complex was declared a Superfund site in 1983 and has been undergoing extensive remediation ever since.

There are many other examples around the United States of problems produced by the smelting of sulfides. Two of the most infamous are in Ducktown, Tennessee, and Palmerton, Pennsylvania. Both destroyed the ecology of the area around the smelters by producing severe acid and metal fallout and



**Diagram showing the steps in refining from mining the ore to the pure metal for manufacturing. Each step produces its own emissions of pollutants, most of which create the worst types of pollution in the world.**

acid precipitation similar to those in Sudbury and Norilsk. Ducktown was a copper-lead prospect, and Palmerton was built to process the zinc ores from Franklin, New Jersey. Both are long since closed; the areas were remediated and have recovered on their own to some extent, but pollution issues remain after all of this time.

See also ACID MINE DRAINAGE; ASBESTOS; BUNKER HILL COMPLEX; CHROMIUM; CYANIDE; LEAD; MERCURY; NICKEL; NORILSK MINE AND SMELTER; SUDBURY MINING AND AIR POLLUTION; SULFUR DIOXIDE.

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**mold** Lately, mold has become a newsworthy pollutant because many public buildings are being closed to treat mold. Schools have been especially vulnerable to it, and numerous academic programs have been disrupted to allow workers to remediate the problem. For this reason, mold has become one of the most addressed indoor pollutants of the 21st century. Perhaps this interest is long overdue, as mold and mildew are becoming increasingly prevalent in homes, as well, to the point where the number of people sensitive to them is increasing dramatically. Mold and mildew may be partially responsible for the current increase in respiratory illnesses among children. They can infect an entire house and require many thousands of dollars for removal. There are several factors in the life cycle of mold and mildew that make them such a health threat, especially their method of reproduction and their preferred habitats.

### SOURCE AND DISTRIBUTION

Mold and mildew are members of the fungi kingdom, which also includes mushrooms and yeast. There are between 50,000 and 250,000 species of fungi, but fewer than 200 have the ability to cause infections in humans. There have been more than 1,000 species of mold found in homes within the United States, but only a few are associated with health problems. It is the reproduction process of mold that makes it a health concern. As with other fungi, mold reproduces by releasing spores. The spores are light enough to travel through air and resistant enough to survive many adverse conditions. They can, therefore, become a significant component of indoor air pollution, where the enclosed space with limited circulation prevents dilution with fresh air as in outdoor conditions.

Another reason that mold and mildew are so successful in homes and buildings is that they thrive in wet, moist, and humid conditions. They can grow on

dust particles, paints, wallpaper, insulation, ceiling tiles, wood, paper, cardboard, carpet, upholstery, fabric, and foods. They grow wherever there are significant moisture and sustenance, including in kitchens, bathrooms, humidifiers, and dehumidifiers; around pipes, leaky roofs, and vents; and in some heating and air-conditioning systems. They are also common on the exterior wall surfaces of corner rooms in climates where heating is required as a result of condensation, and they create particular problems after any type of flooding. The resulting indoor mold and mildew after a minor flood can cause almost as much damage as the water itself.

Mold and mildew enter a building through open doorways, windows, vents, and some heating and air-conditioning systems, or they can be carried in on clothing, shoes, pets, firewood, and other items that have been exposed to outdoor air. Once inside, new tightly sealed buildings that do not allow moisture to escape make perfect incubators for the growth of mold and mildew. That is one reason that the mold and mildew problem has increased over the past few decades. The other reason is that delayed or insufficient maintenance can encourage growth as well. Temporary structures such as trailers and portable classrooms are also particularly susceptible to problems; that is another reason that it is showing up in schools with such regularity.

### HEALTH EFFECTS FROM EXPOSURE

For the people who are sensitive to mold and mildew, in most cases, exposure results in nasal stuffiness, throat irritation, coughing or wheezing, eye irritation, or, in some cases, skin irritation. There are, however, several types of mold that may have different effects on different people, including severe effects. The term *toxic mold* used to describe severe effects is a misnomer. They can produce toxins and especially mycotoxins, but the mold itself is not toxic or poisonous. In fact, bread mold was the origin for penicillin, which began antibiotic medicines and the ability to fight infection. In that regard, mold has benefited far many times more people than it has damaged.

The most common types of molds are *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria*; *Stachybotrys chartarum* is less common. *Aspergillus fumigatus* or *A. flavus* can be dangerous to certain groups. In people who have immunosuppression disorders, complications induced by mold may include invasive pulmonary infection, usually with fever, cough, and chest pain; the infection may spread to other organs including the brain, skin, and bones. People who have chronic obstructive

pulmonary disease (COPD) or other lung diseases including asthma may contract localized pulmonary infections. People who have severe, prolonged granulocytopenia, such as hematologic malignancy; hematopoietic stem cell or solid organ transplant recipients; and patients on high-dosage corticosteroids are at high risk for mold-related complications. Persons who have human immunodeficiency virus (HIV) infections may also be at risk. If severe disseminated infections persist, the mortality rate can be very high for many patients and 100 percent for those who have cerebral abscesses.

A specific disease caused by repeated exposure to mold is called farmer's lung. It is a form of hypersensitivity pneumonitis that is caused by the species *Thermoactinomyces vulgaris*, which is a fungus found in moldy hay or straw or on grain dust. Farmer's lung occurs in 0.5–9.6 percent of farming populations and has been reported in the United States, Canada, France, Norway, Sweden, and parts of several other European countries.

The less common species *Stachybotrys chartarum*, also known as *Stachybotrys atra*, is a greenish black mold that was potentially linked to an outbreak of pulmonary hemorrhage or idiopathic pulmonary hemosiderosis in very young children in 1994. In addition to this condition of acute bleeding from the lungs, a connection between mold exposure and memory loss and lethargy has been proposed but not verified. There is also a strong indication that mold may produce some types of cancer. Aflatoxins and ochratoxin A are toxins produced by mold that have been classified by the National Institutes of Health, National Toxicology Program as human carcinogens. Cancer of both the liver and kidneys has been shown to be significantly increased by long-term repeated ingestion of these toxins. This is one of the few cases of health issues related to mold in which the exposure is not through inhalation.

### MOLD PREVENTION

There are no regulations regarding acceptable levels of mold in homes and buildings. There are mold spores in most homes. The goal is to prevent them from forming surface colonies. Humidity should be kept between 40 and 60 percent, and mold inhibitors should be added to paints in moist rooms. Otherwise, all wet areas should be dried as soon as possible and mold and mildew should be washed away. Ventilation systems should also be cleaned and treated regularly. These prevention steps are especially important in homes where people are at high risk for infection.

See also AIR POLLUTION; INDOOR AIR POLLUTION.

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**Molina, Mario J. (1943– )** *Mexican Environmental Chemist* There are only a few cases when a scientific researcher finds the cause of a major global problem, and the whole world acts to address it. This, however, is exactly the case for Mario Molina. He began research on a relatively bland topic of chlorofluorocarbons (CFCs) and their interactions with atmospheric gases in 1973. It was a relatively open field because CFCs are relatively inert in the lower atmosphere and few researchers expected any interesting science from it. Even though he had no reason to believe that these inert chemicals were a problem, Molina showed that at high altitudes solar radiation could dissociate the CFCs, producing free chlorine radicals. It was these chlorine radicals that Molina and his associate F. Sherwood Rowland believed would catalytically destroy ozone. They published their results on June 28, 1974, in the prestigious journal *Nature* to moderate interest.

It was in 1984 that several scientists were shocked to discover a huge hole in the ozone layer over Antarctica. Although CFCs had already been implicated in ozone depletion both by Molina and by subsequent researchers, some people still did not believe that CFCs were the cause of the problem. Mario Molina went back to his lab and proved that CFCs were the cause and developed a full model to explain the process. As a direct result, CFCs were immediately banned from many applications such as aerosol propellants and phased out of others such as refrigerants on a nearly global basis. As a result of this scientific research, society was changed. For his efforts, Mario Molina received the 1995 Nobel Prize in chemistry, which was shared with F. Sherwood Rowland and Paul Crutzen, another researcher of ozone depletion.

In addition to his groundbreaking work on ozone, Mario Molina works on the chemistry of aerosols in the atmosphere and photochemical reactions in the atmosphere. He is also considered an expert on air pollution over megacities in the developing world. Considering that he grew up in Mexico City, one of the most notorious examples of a highly polluted megacity, his research interests are not surprising.

### BIOGRAPHICAL INFORMATION

Mario J. Molina was born on March 19, 1943, in Mexico City, Mexico. His father, Roberto Molina Pasquel, was a lawyer and university instructor, who later served as the Mexican ambassador to Ethiopia, Australia, and the Philippines. Mario Molina attended elementary school in Mexico City and lived quite comfortably. His aunt, Esther Molina, was a chemist, and he developed his love of chemistry through her. When Mario was 11, he was sent away to boarding school in Switzerland but was dismayed when his classmates there had no more interest in science than his friends in Mexico. In 1960, he completed high school and enrolled in the chemical engineering program at the Universidad Nacional Autonoma de Mexico, the same school where his father had taught. He would have preferred to study physical chemistry, but it was not offered. When he graduated in 1965, Mario decided to earn a Ph.D. in physical chemistry and enrolled in the University of Freiburg in Germany. After two years of study, he found that the direction he was following was not to his liking and withdrew from the program. He returned to the Universidad Nacional Autonoma de Mexico as an assistant professor in chemical engineering and even began a graduate program for the department but again decided to leave.

In 1968, Mario Molina decided to pursue his true interest in physical chemistry and entered the Ph.D. program at the University of California at Berkeley. He found the exact area that he wished to pursue under the mentorship of George Pimentel. He studied molecular dynamics using chemical lasers in a very active research group that included Luisa Tan, whom he would later marry. He completed his Ph.D. in 1972 and accepted a postdoctoral fellowship from his adviser for an additional year. In fall 1973, Mario obtained a second postdoctoral fellowship, at the University of California at Irvine under F. Sherwood Rowland. It was there that he began his groundbreaking work on CFCs. In 1975, he was appointed to the faculty at the University of California at Irvine as an assistant professor and later associate professor. With all of the teaching

and administration that accompany a faculty position, Mario missed experimental work, so, in 1982, he accepted a position in the molecular physics and chemistry section at the National Aeronautics and Space Administration's (NASA's) Jet Propulsion Laboratory at California Institute of Technology.

By 1989, Mario Molina found that he missed the academic life and joined the faculty at the Massachusetts Institute of Technology as a full professor. In 1997, he became the Lee and Geraldine Martin Professor of Environmental Sciences and remained until 2005. At that point, he was divorced from Luisa Molina and married Guadalupe Alvarez. He also accepted the position of professor at the University of California at San Diego, where he remains today. Another current project of his was the creation of a new center for strategic studies in energy and environment, which Dr. Molina is heading.

### AWARDS

Certainly, the most prestigious award that Mario Molina has received for his work was the 1995 Nobel Prize in chemistry. This is not the only honor he received. In 1994, Molina was named by President Bill Clinton to serve on the 18-member President's Committee of Advisers on Science and Technology. In 1998, he was named as one of the top 20 Hispanics in Technology. In 2003, he received the Ninth Annual Heinz Award for environmental protection and was named one of the outstanding "trailblazers" in science by *Science Spectrum* magazine in 2005. Molina is a member of the U.S. National Academy of Sciences, the National Institute of Medicine, and the Pontifical Academy of Sciences. He has served on the Secretary of Energy Advisory Board, the National Research Council Board on Environmental Studies and Toxicology, and the boards of the U.S.-Mexico Foundation of Science. He was the first person not living in Mexico ever to be inducted into the Mexican National Academy of Engineers.

See also CRUTZEN, PAUL; OZONE.

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**MTBE (methyl tert-butyl ether)** The history of MTBE is quite ironic. MTBE is primarily a fuel additive designed to reduce air pollution, and yet this remedy itself has become an environmental threat. MTBE was introduced in 1979 as an additive to gasoline as a replacement for lead to boost octane. The concentration was greatly increased in 1992 in certain areas to oxygenate the fuel. MTBE raises the oxygen content of the gasoline to help it burn more completely, thus reducing harmful emissions. In the beginning, it was only used in winter months. In 1995, however, to fulfill the requirements of the 1990 Clean Air Act Amendment, reformulated gasoline was required on a year-round basis in certain cities with the highest ground-level ozone concentrations. At that point, about 30 percent of the gasoline sold in the United States had to be reformulated, and of that, about 87 percent was treated with MTBE to resolve the problem. The second phase of the reformulated gasoline program, which expanded the use of MTBE further, began in January 2000. The U.S. Environmental Protection Agency (EPA) reported that as a result of this program, at least 105,000 tons (95,454 metric tons) of smog-forming pollutants and 24,000 tons (21,818 metric tons) of airborne toxins was being reduced annually in the United States, the equivalent of taking 16 million cars off the road. The requirements are that refineries must effect a reduction of volatile organic compounds (VOCs) by 27 percent, airborne toxins by 22 percent, and nitrogen oxides by 7 percent, compared with the gasoline they produced in 1990. MTBE has, therefore, been a benefit to the environment.

### PROPERTIES AND PRODUCTION

MTBE is a VOC that is produced by a chemical reaction of methanol and isobutylene. It was produced at chemical plants in very large quantities, more than 200,000 barrels (31,797,459 L) per day, in the United States alone in 1999. At room temperature, it is a volatile, colorless, and flammable liquid that evaporates quickly and is highly soluble in water. It was an ideal solution to the new strin-

gent requirements for gasoline because it blends well and is easily transported by pipeline or tanker to the refineries.

### RELEASE INTO THE ENVIRONMENT

MTBE has certain characteristics that make it a potent invader of the environment. It dissolves in water readily and does not adhere to organics in soil as many other compounds do. It is also thinner (less viscous) than many VOCs. As a result, when spilled, it can travel faster and farther than the other components of gasoline. It, therefore, reaches water wells and surface water well ahead of a gasoline plume and affects many more residences than does the plume itself. The problem can be especially acute near manufacturing, shipping, and pipeline facilities, although leaking tanks at gasoline stations provide more widespread distribution. MTBE does not degrade readily in groundwater systems, is resistant to bacterial action, and is very difficult and costly to remediate. This is not the case in surface water systems, where it has been shown to evaporate quickly. In the open air, it will break down to other compounds at a rate of one-half of the released volume in four hours.

### HEALTH EFFECTS FROM EXPOSURE

The first indication of health problems associated with MTBE occurred in 1992, when a spill in Fairbanks, Alaska, sickened residents. People complained of headaches, dizziness, eye irritation, burning sensation in the nose and throat, feelings of confusion, and nausea. MTBE is also used to dissolve gallstones in medical procedures. If it leaks into other parts of the body, it will produce the same temporary symptoms in addition to vomiting and a reduction in white blood cells. These would become the common symptoms of MTBE exposure. As a result of these health effects, extensive medical testing on laboratory animals was initiated. When exposed to high levels of liquid or vapor MTBE, some rats and mice died. Vapors further produced irritation to the nose and throat of animals, as well as disruption of the central nervous system. Animals acted as if they were intoxicated, with decreased activity, inability to stand up, and partially closed eyes. These symptoms dissipated within one hour. When animals were exposed to high concentrations of MTBE for extended periods, the symptoms were far more serious. Rats developed kidney disease and, in some cases, cancer of the kidneys. Some male rats developed testicular



cancer, and some female rats developed lymphoma and leukemia. Mice developed enlarged livers and in some cases tumors on the liver, and birth defects increased considerably.

### REGULATIONS ON HUMAN EXPOSURE

In 1997, the EPA concluded that at concentrations of 20–40 parts per billion (ppb) or below, MTBE was unlikely to cause any adverse health effects or even be detectable by taste. In 2000, in an effort to protect the health of children, the EPA issued recommendations that drinking water concentrations of MTBE should not exceed 4 milligrams per liter of water for exposures of one to 10 days and 3 milligrams per liter for longer exposures. In 2001, it became law that most public water supplies had to test for MTBE. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends an exposure limit of 40 parts per million (ppm) of MTBE in air for an eight-hour-workday and a 40-hour workweek. The Energy Policy Act of 2005 removed the 2 percent oxygen requirements for reformulated gasoline and called for the phasing out of MTBE over the next nine years. Many states had already begun substituting ethanol for MTBE.

### CLEANUP OF MTBE

If soil and groundwater are contaminated with MTBE, there are several treatment alternatives. In soil, it is relatively easy to remove, because it is thin and does not adhere to organic particles. The treatment of choice is soil vapor extraction (SVE), which involves drawing air through the soil. The high vapor pressure of MTBE makes it easy to vacuum out. Removing MTBE from water is much more difficult. The standard procedure is to pump the water through granular activated carbon (GAC). The problem is that MTBE does not adhere to the activated carbon readily, so large quantities of water must be pumped through the system many times, and even then it may not all be removed. This procedure is costly and inefficient. Recent laboratory studies using genetically altered bacteria have yielded promising results. This may be the standard treatment in the future.

See also IN SITU GROUNDWATER REMEDIATION; NOX; ORGANIC POLLUTANTS; OZONE; VOLATILE ORGANIC COMPOUND.

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### Muir, John (1838–1914) Scottish-American

*Naturalist* John Muir was the first American environmentalist and is universally regarded as the grandfather of the movement. During a time when progress was the only interest of the vast majority of Americans, he asked that they think ahead and put aside natural wonders for future generations. The idea was so far ahead of its time that it took people by surprise. No one could even fathom that America would ever run out of natural resources or would have to consider protection of the environment. John Muir, however, had walked a great deal of the country and had seen the massive destruction. It was this vision of an America without wilderness that drove him to fight relentlessly for preservation. Through his writings and activism, he began slowly to turn America’s attention toward the environment. It was also primarily through his efforts that the Sierra Club and the U.S. National Park Service were established. These institutions have allowed a huge amount of land to be preserved in its natural state. Many of America’s natural treasures would have been gone without these efforts. The Sierra Club has also participated in significant pollution-reduction efforts. Were it not for John Muir, the environmental health of America would currently be much worse.

### BIOGRAPHICAL INFORMATION

John Muir was born on April 21, 1838, in Dunbar, East Lothian, Scotland. His parents were Daniel Muir and Ann Gilrye, and he was one of eight children. John entered school at the age of three but spent most of his free time fighting and hunting for birds' nests. In 1849, at age 11, John and his family emigrated to the United States and began a pioneer life near Portage, Wisconsin. Life was hard, but John was intent on schooling himself, so he slept a mere five hours a night to have time for his studies. He also made time to invent devices, primarily carved from wood with a pocket knife. He invented many ingenious devices that performed numerous functions including horse feeding devices, wooden clocks, and a thermometer made entirely from wood. In 1860, on the advice of friends, he traveled to the state agricultural fair in Madison, Wisconsin, to exhibit his inventions. His devices attracted so much attention that he was persuaded to enter the University of Wisconsin to continue his studies. He attended the university for five trimesters, or 2.5 years, and there he learned the basic sciences that he would use in his career. Although he had excellent grades, he did not graduate but instead chose to take a trek through Wisconsin, Iowa, Illinois, and part of Canada all by foot.

Muir returned to Indianapolis, Indiana, in 1866, and got a job making carriage parts. After a year at this position, however, he had an accident that temporarily blinded him in his right eye. This accident was a turning point in his life, because he decided that he could not risk never being able to see nature again. After he recuperated, Muir began a 1,000-mile (1,600-km) journey by foot from Indianapolis to the Gulf coast of Florida. From there, he sailed on a boat to Cuba and later to Panama, where he contracted a severe fever, possibly malaria. At that point, he decided to return to the United States and crossed the Isthmus of Panama and sailed up the west coast of Central America and Mexico, landing in California. He arrived in San Francisco penniless on March 28, 1868, and began walking again. He walked across the San Joachim Valley, saw the Sierra Nevada, and visited Yosemite for the first time. That would be his home from then on.

He began working in the area, first at a ranch, then as a sheepherder in the high Sierras, until he settled in Yosemite to operate a mill. Rather than simply using available technology, he put his ingenuity to work and designed a water-powered mill. He also began exploring the area and discovered glaciers in Yosemite. By studying locations and sedimentary deposits, he derived a controversial history for the area that was later confirmed by the famous geologist Louis

Agassiz. He also began writing during this time. Muir made enough of a reputation for himself that between 1871 and 1873 Ralph Waldo Emerson and other famous writers and naturalists sought him out. He was in the Owens Valley earthquake of March 1872 and wrote about the changes that had taken place as a result of the earthquake.

Muir's writing career began in earnest in 1874, when he left Yosemite to live in Oakland, California. He wrote a series of articles titled "Studies in the Sierra." His writings were not only about geology but also about ecology, including groves of giant Sequoias. To broaden his experience and expertise to other regions, Muir joined the U.S. Coast and Geodetic Survey in 1876. This position took him to many areas, including Alaska, where, in 1879, he discovered Glacier Bay and the glacier that would later bear his name. On April 14, 1880, at 42 years old, he married Louie Wanda Strentzel and moved to Martinez, California, where he and his wife raised two daughters. There, Muir entered a partnership with his father-in-law to manage the family fruit ranch in 1882 and, as usual, was very successful. Before the ranching period began, however, Muir was able to make one more trip to Alaska as a member of the Corwin Expedition in 1881. On this trip, he did extensive study of glacial formations and features, both along the Bering Sea and along the coast of Siberia.

After spending many years managing the ranch, building the Muir mansion, raising a family, and continuing his writings, John Muir began his excursions again with a trip to Mount Rainier. That year he edited a two-volume book titled *Picturesque California*. It was during this period that Muir began to become concerned about human encroachment on and destruction of his beloved wildlands. Although he had always been a scientist and naturalist, it was then that he became an activist. His main concentration was on preservation of the natural environment and the creation of a government institution to ensure it. He wrote a series of articles in 1889 urging the creation of a federal preserve around Yosemite, which took place the following year, when on September 30, 1890, Congress voted to make it a national park. Encouraged by this success, he pushed on and was the main force behind the creation of the Sierra Club on May 28, 1892, for which he served as president until his death in 1914. The first effort of the new club was to preserve the full size of Yosemite, which was under attack by logging and other groups that wanted to exploit the land rather than preserve it.

John Muir continued his excursions and scientific studies, but it was his activism and writing that took center stage and for which he is best known. He was personally involved in the creation

of national parks at Sequoia, Mount Rainier, Petrified Forest, and Grand Canyon, in addition to Yosemite. Muir fought for preservation of wildlands while others of his time fought for conservation, a less extreme philosophy, which resulted in a rift in this early environmental movement. Although some of Muir's excursions, such as a trip to Scandinavia in 1893, were motivated by personal interest, other excursions became more political. He was asked in 1899 to join the famous Harriman Expedition to Alaska because of his scientific and literary expertise, but he also befriended Harriman and later used his connection with him to apply pressure to Congress to pass additional preservation legislation. In 1901, Muir published his book *Our National Parks*, which caught the attention of President Theodore Roosevelt. In 1903, Roosevelt traveled to California to meet with Muir at Yosemite. It was there that Muir influenced Roosevelt's innovative and extensive conservation programs, including five national parks, 23 national monuments, and the preservation of 148 million acres (60 million ha) of national forest.

John Muir continued to write and travel but, in his later years, suffered several major setbacks. In 1906, the great San Francisco earthquake caused extensive damage to his house, which took time to repair. On August 6 of the same year, his wife of 26 years died. In 1907, he would become embroiled in a fight to save the Hetch Hetchy Valley above San Francisco. It was slated to be dammed to make a reservoir for the city, but Muir, referring to it as a second Yosemite, was adamant that it should be preserved for its beauty. The battle over it lasted six grueling years, and, ultimately, in 1913, the dam was built. Muir took a trip to South America and traveled 1,000 miles (1,600 km) up the Amazon basin, as well as an excursion to Africa in 1911 and 1912, at the age of 73. John Muir died of pneumonia on December 24, 1914, at the age of 76.

## HONORS AND AWARDS

During his career, John Muir was the author of 10 major books and more than 300 articles, 150 of which were in magazines and newspapers and designed to enlighten and persuade readers about conservation and preservation. As a result of his prolific writing and influence, John Muir was awarded an honorary degree of master of arts by Harvard University in 1896, an LL.D. degree by the University of California in 1896, an LL.D. degree by the University of Wisconsin in 1897, and a doctor of literature degree by Yale University in 1911. In addition to the Muir Glacier, there are two John Muir Trails (California and Tennessee), a John Muir Wilderness (California), and a Muir Woods National Monument (California). There are an asteroid named after him, an image of him on the California state quarter, and a John Muir Day on April 21 in California. Perhaps the greatest tribute to him was, in 1916, two years after his death, the establishment of the U.S. National Park Service, for which he had lobbied so forcefully.

See also SIERRA CLUB.

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# N

**naphthalene** Naphthalene is a very hazardous substance that is almost ubiquitous in everyday life. It is in all coal tar products from creosote and other wood preservatives to road tar and asphalt. It is released from coal burning and processing plants including power plants, coke ovens, metal smelters, and refineries, in addition to petroleum refineries. It is also released to the air from burning wood and tobacco. Even if it were only slightly toxic, it would still be dangerous by virtue of its dispersal. It is, however, toxic and therefore very dangerous. Naphthalene is also known as naphthalin, naphthaline, tar camphor, white tar, albocarbon, and naphthene. Naphthalene and its metabolites 1-methylnaphthalene and 2-methylnaphthalene have been identified in 654, 36, and 412, respectively, of the first 1,662 U.S. Environmental Protection Agency (EPA)–designated Superfund sites on the National Priority List where it was tested. Naphthalene was rated number 78 of the 275 most dangerous chemicals on the 2007 CERCLA Priority List of Hazardous Substances, and 2-methylnaphthalene was rated number 157 of 275. It is the physical and chemical properties of naphthalene that make it a health and environmental risk.

## PROPERTIES, USE, AND PRODUCTION

Naphthalene is a polycyclic aromatic hydrocarbon (PAH) that occurs naturally in petroleum and coal tar. In its pure state, it occurs as white scales, powder, balls, or cakes with a strong mothball odor. The 1-methylnaphthalene metabolite is a clear liquid, and 2-methylnaphthalene is also a white solid; they are similar in odor and other properties. Naphthalene is best known for its use in the production of mothballs, moth flakes, and toilet deodorant blocks. It is much

more commonly used in the production of chemicals and especially phthalic anhydrite, which is used to make plastics. Other uses include the production of pharmaceuticals, insect repellants and insecticides, leather tanning chemicals, dyes, synthetic resins, celluloid, lampblack, smokeless powder, solvents, lubricants, anthelmintics, and intestinal antiseptics. In 1999, 59 percent was consumed in the production of phthalic anhydrite, 21 percent in production of surfactants and dispersants, 11 percent in production of insecticide, and 9 percent in moth repellants and all other applications. It is no longer used in tanneries, in textiles, or in toilet bowl deodorizers.

Naphthalene was first isolated in 1819, but it was not named until 1821, and the chemical formula was not determined until 1826. Most naphthalene originates in coal tar, but from the 1960s to the 1990s, a large portion was derived from petroleum refining. Production of naphthalene in the United States peaked in 1968 at 900 million pounds (408,000 metric tons) but decreased into the 1990s to 222 million pounds (101,000 metric tons). Production has remained relatively steady in recent years, increasing slightly to 235 million pounds (107,000 metric tons) by 2000, 90 percent of which (219 million pounds [99,000 metric tons]) was from coal tar. Imports of naphthalene fluctuated in the United States in recent years, from a high of 40.9 million pounds (18.5 million kg) in 1989 to a low of 2.5 million pounds (1.1 million kg). In 2003, imports totaled 15.2 million pounds (6.9 million kg).

## ENVIRONMENTAL RELEASE AND FATE

Naphthalene is released to the environment as a point source pollutant from industry, transportation,



or storage; from spills or leaks; or from improper disposal. It is more commonly a nonpoint source pollutant, primarily from the residential burning of wood and fossil fuel, cigarette smoke, moth repellants and insecticides, and the degradation of wood preservative and road tar. When released into the air, naphthalene breaks down quickly by photolysis and reaction with hydroxyl radicals, typically within one day. When released into surface water, most naphthalene evaporates at the surface, but some dissolves, and it is commonly found in rivers and lakes. Subsurface removal results primarily from microbial activity and is complete within about two weeks. Once released into the soil, most naphthalene evaporates into the air, but that which remains is relatively mobile. It binds only weakly to soil and sediments depending upon their chemistry, allowing much of it to leach into groundwater systems. Naphthalene is removed from soil and groundwater primarily by biodegradation in about one to three months. It is not particularly persistent in the environment.

In the EPA Toxics Release Inventory (TRI) for 1998, the total release of naphthalene by industry to the environment was reported to be almost 6 million pounds (2,700 metric tons). By 2001, reported release had decreased to just over 2.6 million pounds (1,200 metric tons), of which more than 75 percent was released into the air. In 2005, the total release was back up to 3.82 million pounds (1.7 million kg). In 2006, the total off-site industrial release of naphthalene was 1,233,332 pounds (560,605 kg).

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects that result from exposure to naphthalene. Acute exposure produces neurotoxic effects, such as fatigue, confusion, lethargy, listlessness, loss of appetite, and vertigo, as well as gastrointestinal effects, such as nausea, vomiting, diarrhea, and blood in the urine. It also produces pale to yellow discoloration of the skin as well as skin and eye irritation and hemolytic anemia, a condition in which the red blood cells are damaged. People of Mediterranean and African heritage are especially susceptible to hemolytic anemia. Very high doses may result in death. Long-term, chronic exposure to naphthalene results in lung damage, cataracts, decreased body weight, damage to the lining of the nose, and kidney, liver, thymus, and spleen damage. Naphthalene can also cross the placenta in pregnant animals and cause fetal toxicity.

The U.S. Department of Health and Human Services classifies naphthalene as “reasonably anticipated to be a human carcinogen,” whereas the U.S. Environmental Protection Agency classifies it in group C—as a

possible human carcinogen—as does the International Agency for Research on Cancer (group 2B). Naphthalene has been shown to cause a rare but highly malignant cancer of the nasal passages that can spread to the brain in rats. It has also been shown to increase the incidence of lung tumors in some animals. Human epidemiological studies suggest that it could increase colorectal cancer and cancer of the larynx.

### REGULATIONS ON HUMAN EXPOSURE

Federal regulatory agencies limit exposure to naphthalene. The EPA recommends that naphthalene in drinking water be limited to 0.1 part per million (ppm) averaged over a lifetime of exposure and that children should not drink water with 0.5 ppm of naphthalene for more than 10 days or 0.4 ppm for more than seven years. They further require the reporting of environmental releases of 100 pounds (45.5 kg) or more of naphthalene to the National Response Center. The Occupational Safety and Health Administration (OSHA) lists a maximal permissible exposure limit (PEL) of 10 ppm in air for an eight-hour-workday, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) has set a recommended exposure limit (REL) of 10 ppm, a short-term exposure limit of 15 ppm, and an immediately dangerous to life and health (IDLH) limit of 250 ppm of naphthalene in air. NIOSH estimates that some 112,700 American workers were exposed to naphthalene from 1981 to 1983.

See also ORGANIC POLLUTANTS; PAH; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE.

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**National Zinc Bartlesville, Oklahoma (1991–2001) Soil Pollution** Zinc is an essential trace element or micronutrient for humans, animals, and plants and is included in most vitamin supplements. This minuscule amount plays a key role in the formation of hundreds of enzymes, regulating growth rates in children and young adults, and in immune system performance. As an industrial metal, zinc most often is mined as a coproduct with lead. Lead is used primarily in batteries and zinc in galvanizing. The excellent corrosion-resistant properties of zinc increase the service life of iron or steel in structural beams, roofing materials, and other objects exposed to weather. In galvanizing, steel objects are dipped into a vat of molten zinc and coated with a thin layer, usually 3 mils, or 0.003 inch (0.08 mm) thick. Zinc coatings are inexpensive, easy to apply, and maintenance free and can last for 40 years or more. About half the industrial demand for zinc is for galvanizing steel and other metals, but other applications include use as an alloying agent in metals such as brass and in chemical production. On an annual basis, a little more than 7.7 million tons (7 million metric tons) of zinc is extracted and processed from mines around the world.

The United States is the world's dominant producer of zinc, with 10 major mines in five states operated by seven companies. Mines in Alaska, Missouri, and Tennessee account for 97 percent of 770,000 tons (698,532 metric tons) of domestic production. Most U.S. production is from the Red Dog Mine in Alaska, but an important ongoing and historic source of zinc has been the area around the tristate mining district of Kansas, Missouri, and Oklahoma in the drainage basin of the Mississippi River. Within this region zinc and lead-bearing minerals of sphalerite and galena are part of sedimentary rocks. The ore bodies are contained in dolostone host rocks. These types of deposits are known generically as Mississippi Valley type, or MVT, ore bodies and account for 10–20 percent of the world's zinc

and lead mineral reserves. Mineralization is most often found in the open pore spaces of broken and crushed rock and as filling in fractures.

## INDUSTRIAL CONTAMINATION

In 1902, a company called Horseheads Industries, later National Zinc Corporation, began to exploit MVT zinc-lead deposits near Bartlesville, Oklahoma, about 45 miles (72.4 km) north of Tulsa. The first step used by National Zinc in refining its ore was to roast it to remove sulfur. It then was loaded into one of three horizontal retort zinc smelters that were in operation within or near Bartlesville. This process, developed by a Flemish priest in the mid-1800s, requires the use of numerous flask-shaped vessels. They are loaded with roasted or calcined zinc ore, typically about 1,000 pounds (454 kg); mixed with charcoal; and heated in a furnace. The zinc is driven off, or volatilized, and collected in a distillation vessel. Impurities such as lead, cadmium, and arsenic are also present in the gases, but in the past these gases were not collected or collected only periodically and most commonly were vented directly into the atmosphere. In the United States, Belgian furnaces of this type were built to hold 300–800 retorts. By the 1920s, two of the three horizontal retort smelters at National Zinc had ceased operation, and in 1976 the third smelter (which is now inactive) was converted to one using a more efficient electrolytic process.

Over the almost 70 years of zinc ore processing, the retorts operated without any or only minimal air pollution controls, and the metal-laden dusts and fumes that were emitted from the process vessels were discharged into the air around Bartlesville, eventually settling within an approximate three-mile (4.8-km) radius of the western side (downwind) of the National Zinc plant. These materials contaminated the soil and surface water with lead and, to a lesser extent, arsenic, cadmium, and zinc. In addition to air emissions, other sources of the metallic contaminants found in the Bartlesville environment (population about 40,000) include ore concentrates delivered to the facility by railcar, dust from the transport and storage of ore concentrates, and solid waste materials at the facility. The impacted area includes properties used for residential, commercial, industrial, recreational, and agricultural purposes. Wildlife habitat in undeveloped land is also present within the contaminated zone, and portions of the site are within the floodplain of the Caney River, the major surface water drainage system in the area.

In 1991 and again in 1992, responding to public concerns about the potential for lead exposure, the

Agency for Toxic Substances and Disease Registry (ATSDR), in cooperation with the Oklahoma State Department of Health (OSDH), collected blood samples from residents living both west and east of the National Zinc plant and analyzed them for lead levels. Findings indicated that approximately 14 percent of the children living to the west of the facility had blood lead levels greater than 10 micrograms per deciliter (mcg/dL). This is the concentration set by the Centers for Disease Control and Prevention as the indicator for potentially elevated blood lead levels. A control group of children, from areas of Bartlesville that are not in the vicinity of the site, had no incidence of blood lead levels exceeding 10 mcg/dL.

Children up to six years of age are the most sensitive to metal contamination in soil because during play and time outdoors, they tend to ingest soil. The concentrations of lead in soils downwind of National Zinc have been measured to be as much as 1.6 percent (16,000 mg/kg). These elevated concentrations presented an unacceptable risk of exposure that could result in developmental problems for children ranging in age from six months to six years. While not life threatening, these developmental problems could include learning disabilities, attention deficit disorder, and hearing loss.

Similarly, exposure to and accumulation of cadmium in the body can cause kidney damage and hypertension. Several studies also connect increased cadmium levels in the body to certain kinds of cancer. Concentrations of cadmium in soil downwind of National Zinc were present at up to 3.4 percent (34,000 mg/kg). Widespread elevated levels of arsenic were not found during site characterization studies, but the U.S. Environmental Protection Agency (EPA) established a goal for this contaminant during remediation in case it was found during cleanup efforts. A similar remedial goal for zinc was set because although zinc does not pose a significant threat to human health in most cases, it can damage sensitive ecological receptors at elevated levels, particularly in aquatic areas. High levels of zinc also can interfere with plant growth and result in damage to leaves and fruit.

### REMEDIATION EFFORTS

On the basis of these and other data, the EPA recommended the National Zinc property for inclusion as a Superfund site on the National Priorities List in 1993. Later that year, EPA directed the removal of contaminated soil in 25 residential “high-access areas,” including backyards, playgrounds, and schoolyards. Contaminated soil found in 10 more

nonresidential high-access areas also was removed. Using criteria developed as part of a site-specific risk assessment, the EPA established soil cleanup goals of 925 mg/kg for lead, 100 mg/kg for cadmium, and 60 mg/kg for arsenic.

There was a second round of soil removal in 1994. These efforts were focused on residential properties where at least one soil sample contained elevated concentrations of metals greater than 925 mg/kg of lead, 100 mg/kg of cadmium, or 60 mg/kg of arsenic. Once the contaminant was removed, the excavated area was refilled with clean soil and covered in sod. A third round of removal actions at impacted residential properties took place in 1995. The contaminated soil was isolated from the environment at commercial properties, by capping or covering it with clay, asphalt, or concrete, or by mixing the near-surface contaminated materials with deeper, underlying clean soil, and/or by adding phosphate to bind or chemically fix the metallic ions to the soil. Contamination that had made its way into the sediments of stream channels and local watercourses on the west side of the plant also was excavated. Excavated materials were shipped to a properly licensed off-site disposal facility.

In 1995, as remedial activities were being undertaken at National Zinc, ATSDR and OSDH reran the voluntary blood lead level testing program for children from infants to five-year-olds and repeated this testing annually until 2001. No elevated blood levels were reported in children from 1998 to 2001.

See also ARSENIC; CADMIUM; LEAD; SOIL POLLUTION; SUPERFUND SITES; ZINC.

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**Nevada Test Site Mercury, Mojave Desert, Nevada (1951–1992) Soil and Water Pollution**

The Nevada Test Site, or NTS, a 1,400-square-mile (3,584-km<sup>2</sup>) restricted access area, served as the United States' continental testing ground for the development of its nuclear weapons arsenal. Carved out of a larger tract of almost 5,500 square miles (14,245 km<sup>2</sup>) of unpopulated Mojave Desert, NTS also acts as a military gunnery range, is adjacent to the notorious Area 51 of UFO fame, and is used regularly as a massive outdoor laboratory and experimental center for everything from testing of hazardous spill response technologies to ecological habitat protection techniques.

There are 400 miles (644 km) of paved roads and 300 miles (483 km) of unpaved roads on the property, along with two airstrips capable of receiving jet aircraft, 10 heliports, an independent water supply, and electrical distribution systems. Along the south-central border of the site, the small town of

Mercury, Nevada, was established as a “base camp” and contains many of the facilities present in most municipalities such as housing, medical services, fire protection, a post office, law enforcement, and a restaurant. There are more than 1,100 buildings within NTS, including a fully equipped motor vehicle maintenance and repair shop.

### NUCLEAR TESTING

Beginning in 1951 and continuing until 1992, when the United States began to honor, although never officially ratifying, most of the articles of the Nuclear Test Ban Treaty, there were 925 nuclear tests at the Nevada Test Site. Of these, 100 were aboveground, or atmospheric, tests and 825 were belowground. Explosive yields ranged from 500 kilotons to one megaton, equivalent to the energy released by detonating 500,000 tons (454,000 metric tons) to 1 million tons (0.9 million metric tons) of trinitrotoluene



Craters from the detonation of nuclear bombs at the Nevada Test Site (U.S. Department of Energy/Photo Researchers, Inc.)



(TNT). Data from research and university seismographs collected during this period indicated that there also were numerous unannounced or secret tests.

In atmospheric, or aboveground, tests a nuclear explosive device was detonated while on the ground surface, on a steel tower, suspended from tethered balloons, dropped from an aircraft, or placed on a rocket. Underground tests took place by drilling a vertical shaft into bedrock, placing the nuclear explosive device inside the shaft, sealing the shaft with concrete, and then detonating the device. Approximately one-third of the more than 800 belowground devices were exploded near or below the water table. Underground testing was preferred because the explosive forces and fireball were more readily contained and the release of radioactivity to the atmosphere was minimized. In addition, underground testing allowed the placement of a much wider range of scientific measurement and experimental apparatus closer to the explosion.

Troops were stationed within a few miles of these explosions to allow the Defense Department to evaluate military preparedness in the event of wartime exposure to nuclear weapons and radioactive fallout. The NTS tests were performed only 65 miles (104.6 km) from Las Vegas. In the 1950s and 1960s, tourists traveled to the city to see the impressive mushroom-shaped clouds that were visible on the horizon.

### **POLLUTION AND REMEDIATION OF THE SITE**

A 1997 report by the National Cancer Institute later found that the atmospheric tests conducted at NTS between 1952 and 1957 resulted in the deposition of elevated levels of radioactive iodine 131 across most of the United States. Health effects from iodine and other radioactive isotopes released or created by these tests were concentrated in population centers downwind of NTS. As a result, in 1990, the U.S. Congress passed the Radiation Exposure Compensation Act, which established a fund to compensate nearby residents afflicted with certain types of illnesses that might have been caused by fallout from NTS testing activities. By 2006, almost 11,000 of these types of claims had been approved, and more than \$525 million in compensation had been awarded to NTS “downwinders.”

Currently, the U.S. Department of Energy (DOE) National Nuclear Security Administration Nevada Site Office is responsible for the management and operation of NTS. In cooperation with the state of Nevada, the DOE and Department of Defense (DOD) have conducted a series of investigations to

identify approximately 1,700 areas, called Corrective Action Sites and Correction Action Units (CASs and CAUs), where either surface or subsurface radiological contamination, including groundwater contamination, has been confirmed and delineated.

Of the confirmed 825 belowground nuclear tests carried out at NTS, approximately 275 were exploded near or below the water table. Contamination of groundwater has resulted in some areas of the NTS. These areas of known and potential groundwater contamination due to underground nuclear testing are called Underground Test Area (UGTA) CAUs. Approximately 57 million curies (Ci) of radioactive tritium remains belowground from the tests. A curie is the traditional measure of radioactivity: of 37 billion particles (disintegrations) given off every second. This is roughly equivalent to the radiation given off by 1 gram of radium 226. Curies have been replaced by the more widely used unit the becquerel, which is equal to one disintegration per second.

Tritium is a radioactive isotope of hydrogen that contains one proton and two neutrons; by contrast, standard hydrogen has one proton and one neutron. Tritium emits low-energy beta radiation that cannot penetrate skin. It is only harmful if inhaled or ingested. It readily combines with oxygen to form tritiated water, which is very mobile in the environment. Fortunately, as a result of tritium’s relatively short half-life of 12.3 years, if it can be contained for 123 years (10 half-lives), it does not represent a significant health risk.

Tritiated groundwater at NTS is found in six UGTA CAUs distributed along the northern and eastern sides of the site. Groundwater emanating from these UGTA CAUs generally flows to the south and southwest. In this area, the top of the water table is more than 500 feet (152.4 m) below the surface. There is no technology available for the cost-effective cleanup of this deep, extensive groundwater contamination. The NTS environmental monitoring program aggressively tracks the occurrence and movement of this contamination to help ensure that it will not affect downgradient groundwater users. The NTS remedial strategy for groundwater is to allow natural radioactive decay processes to operate and reduce the toxicity of the contamination. If an off-site groundwater user is threatened by the contamination, an alternate source of water will be provided. The tritium should decay to No Action levels by 2115.

More than 7 million cubic feet (203,914 m<sup>3</sup>) of contaminated surface soil containing radioactive americium 241; cesium 137; plutonium 238, 239, and 240; and strontium 90 has been detected at lev-

els in excess of 1,000 picocuries per gram (pCi/g) at 87 CASs on and around the NTS. These radioactive isotopes emit alpha, beta, and gamma radiation that, if inhaled or ingested, can result in cancer and other adverse health effects. Gamma radiation can penetrate skin and even certain types of metal shielding. The action level set by both DOE/DOD and the state of Nevada is 1,000 pCi/g, above which remediation or control measures become necessary to ensure an adequate level of protection for the public health. Soil cleanup levels at most other radiologically contaminated sites, those that are more accessible to the public or have a greater potential for the movement or migration of contaminants off-site, typically have action levels in the 3–50 pCi/g range. By 2007, three soil-contaminated CAS sites on NTTR were cleaned through excavation and removal. The remaining sites, both on and off the NTS property, are in the process of being remediated and restored.

### RESIDUAL RADIATION AND EXPOSURE

More than 80 percent of the ionizing radiation that people are exposed to in the United States is produced by natural sources. Ionizing radiation, which if emitted as unstable isotopes converts or decays to more stable atoms, consists of high-energy electromagnetic waves or particles that are capable of damaging cellular tissue.

Dosage is a measure of the amount of radiation a person receives. The higher the dose, the greater the amount of energy taken into the body and the larger the number of potential cellular molecules disrupted. A measure of the biologic risk of the energy received is the dose equivalent, and the units of dose equivalent are called rems, or, the more modern term, sieverts (Sv). One-thousandth of a rem is called a millirem, and in the United States, the average person receives about 300 mrem each year from natural sources and an additional 60 mrem from medical procedures, consumer products, and other activities.

It is not known whether there is a “safe” radiation dose equivalent, and most regulatory agencies take a conservative approach, assuming that there is no such thing as a 100 percent safe dose equivalent. They further assume that the risk of developing an adverse health effect, such as cancer, is proportional to the amount of the dose. Many human activities increase exposure to radiation above average background levels of 300 mrem/yr, and regulators balance the benefit of these activities to the risk of radiation exposure above background. The DOE has set the dose limit to the public from exposure to DOE-related nuclear activities to 100 mrem/yr (1 mSv/yr), which is the same public dose

### SOURCES OF RADIATION EXPOSURE

Source	Radiation
Five-hour jet plane ride	3 mrem
Building materials	4 mrem
Chest X-ray	8 mrem
Cosmic rays	30 mrem
Soil (naturally occurring isotopes)	35 mrem
Mammogram	138 mrem
Radon gas (from natural sources)	200 mrem
Computed tomography (CT) scan	2,500 mrem
Smoking (pack/day)	5,300 mrem (to lung)
Cancer treatment	5,000,000 mrem (to tumor)

Radiation sickness in humans occurs at short-term exposures of 100,000 mrem or more.

limit set by the U.S. Nuclear Regulatory Commission (NRC) and recommended by the International Commission on Radiological Protection and the National Commission on Radiological Protection and Measurements.

Although testing of nuclear weapons at NTS ceased in 1992, airborne radioactive contamination still occurs; it is due to the resuspension of contaminated dust and debris from areas where devices were detonated and from ongoing operation and maintenance activities such as waste management. Air quality within and along the boundaries of NTS is monitored continuously, and, since 1992, annual concentrations of airborne radiation have ranged from 48 to 2,000 Ci for tritium, 0.24 to 0.40 Ci for plutonium, and 0.39 to 0.49 Ci for americium. Surrounding communities typically have received radiation doses from NTS air emissions that are less than 1 percent of natural background, less than 3 mrem/yr.

In addition to soil, air, and groundwater, there are more than 1,600 sites containing pieces of large, discarded equipment that are contaminated by past nuclear testing activities. Over the past 10 years, the NTR environmental restoration program has been slowly and steadily decontaminating or safely disposing of the material at these sites, and only a few hundred remain. Remedial and other types of operational and maintenance activities have produced low-level radioactive waste (LLRW). In addition, historic NTS missions of research and testing

of nuclear-powered furnaces, rockets, and even airplanes have generated high volumes (thousands of cubic yards) of LLRW. These and similar materials taken to the site from other DOE facilities have been stabilized and permanently disposed of in two specially designed radioactive waste management areas on the site.

These disposal sites accept DOE LLRW from around the country, generated primarily by the cleanup of facilities where nuclear weapon components were manufactured and from DOD sites with a national security classification such as missile silos. LLRW is placed in unlined cells or trenches and covered with up to eight feet (2.46 m) of soil. For waste that may require more careful handling, a large-diameter borehole is drilled, into which drummed or specially boxed waste is placed. One area where LLRW is disposed of is within seven craters that make up five disposal cells. These craters were formed by underground weapons tests and are used for disposal of bulk LLRW waste including soil, debris, and waste in large cargo containers.

See also AQUIFER; RADIOACTIVE WASTE; RADIUM; RADON; SOIL.

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**New York City, air quality of New York, New York (1945–present) Air Pollution** In 1930, the population of New York City was 6.7 million, and by 1960 it had grown to more than 7.8

million, a 15 percent increase. In the 1940s through 1950s, New York State's \$25 billion economy, which accounted for almost 8 percent of the U.S. gross domestic product, had a robust and expanding industrial sector, one that provided high-paying employment in textiles, consumer products, and construction to World War II veterans returning from Europe and the Pacific. Along with the boroughs of Brooklyn, the Bronx, Queens, Manhattan, and Staten Island, the housing stock on Long Island and in the surrounding suburban areas was expanding quickly to accommodate the growing "baby boom," and New York City's public school system was widely regarded as one of the finest in the United States.

This type of rapid economic and population growth has an environmental price. In the case of New York City, it was air pollution. New York City's geography had helped it to avoid the air pollution disasters that had occurred in many other industrial and urban centers such as London; Donora, Pennsylvania; and the Meuse valley, Belgium. Much of the city lies within a few miles of Long Island Sound and the Atlantic Ocean, and the open, flat-lying topography, relatively evenly distributed annual precipitation, and prevailing westerly offshore breezes combined to dissipate the clouds of particulate and sulfur oxides that were the by-products of the coal and oil being burned in the city. Also helping to limit air pollution was an expanding mass transit system that kept thousands of cars off the roads on a daily basis.

#### POLLUTION OF THE AIR

But by the late 1940s and early 1950s, even these mitigating factors could no longer keep pace with the massive quantities of air pollutants being emitted across the metropolitan area. A series of dramatic air pollution events called the situation to the forefront of public attention, to the point that, by 1965, air pollution was a major issue in the mayoral election campaign of John Lindsay.

Between January 15 and January 24, 1953, a midwinter temperature inversion combined with an almost windless air mass allowed pollutant to climb to dangerously high levels. At the peak of the event, sulfur dioxide (SO<sub>2</sub>) levels were measured at 86 parts per million (ppm), whereas typical SO<sub>2</sub> concentrations were usually in the 0.15–0.20-ppm range. Current SO<sub>2</sub> emission levels are considered unhealthy above 0.14 ppm. The air also had a coefficient of haze, or COH, smoke shade value of 8.4. Usual COH values for New York City were less than 3. COH is a long-standing technique used to measure the concentration of large particulate matter based on its effect on the optical density of filter paper.



Although there are no national or state air quality standards for smoke shade, today a 24-hour average of 2.0 COH or greater is considered unhealthy for sensitive groups such as elderly people or those who have respiratory problems. During and shortly after this air pollution episode, which later articles in local newspapers described as “frightening,” the number of recorded deaths per day was 244, compared to the average of 226 deaths per day. The death rate from January 15 through January 24, 1953, increased across all age groups and over all causes.

A similar, although less severe event occurred between November 27 and December 4, 1962. SO<sub>2</sub> levels peaked at 0.7 ppm, with COH values in the range of 6.5. Several researchers attributed these more moderate pollution loads to the reduction in industrial and commercial activity associated with the long Thanksgiving Day weekend. Although there was no statistically significant increase in the city’s death rate, suggesting a threshold effect, a spike occurred on December 1, with 295 deaths compared to an average of 250.

Even as the intensity of the pollution events decreased, their frequency increased. The following table summarizes some of the more noteworthy air pollution episodes that occurred in New York City between late 1962 and early 1964.

Public health officials and academic researchers studying air quality in New York City during this period found that peaks in mortality rate generally matched peaks in air pollutant concentrations. They also found that these excess deaths were spread across the 45- to 64-year-old age group, as well as those older than 65 years old.

As in many American cities, coal played a major part in generating electricity and powering industry in New York City. World War II spurred the development and use of softer coals with higher sulfur content from West Virginia and Pennsylvania. With a better-coordinated and expanded rail system, this coal became the fuel of choice in the eastern United States. By 1950, New York City was importing and burning more than 27 million tons (24.5 million metric tons) of coal and more than 1.5 million gallons (5.7 million L) of oil. In addition, New York City relied heavily on the use of incinerators to manage its growing solid waste problem. The scarcity of suitable landfill space forced many apartment complexes, hospitals, and commercial buildings to burn their trash. These 30,000 incinerators were often poorly operated and maintained and consequently produced up to 40 percent of the SO<sub>2</sub> and particulate that fouled the city’s air, according to an estimate by New York City’s Department of Air Pollution Control.



Pollution overlying New York City, 2001 (Ray Stubblebine/Reuters/Landov)

### CLEANUP EFFORTS

In many respects, New York City’s attempts to improve its air quality were a reflection of similar efforts ongoing in Detroit, Cleveland, and Los Angeles. The sources of air pollution were well understood, including the burning of inexpensive, sulfur-rich coal and fuel oil, along with the widespread use of low-temperature incinerators. The political will to implement the necessary solutions, however, was not present.

Prior to World War II, air pollution control in the New York City metropolitan area was a mix of local, largely ineffective neighborhood campaigns focused on smoke-belching railroad locomotives or a particular industrial plant. During the war, air pollution control was ignored as all of the nation’s industrial might was brought to bear on producing the equipment and supplies needed to fight its enemies. After the war, attempts to introduce antismoke regulations in 1946, 1947, and much of 1948 that had meaningful penalties and attempts to create a Smoke Control Board within the Department of Housings and Buildings stalled because of only moderate public inter-



## AIR POLLUTION EPISODES BETWEEN 1962 AND 1964

Date	Description	Consequences
December 30, 1962–January 15, 1963	SO <sub>2</sub> —0.5 ppm COH—6	330 deaths recorded compared to an average of 270
January 29, 1963–February 13, 1963	SO <sub>2</sub> —0.7 ppm COH—7	330 deaths recorded compared to an average of 260
April 12, 1963–April 25, 1963	No reported increase in SO <sub>2</sub> or particulate values	temperature inversion occurred along with a slight increase in mortality
February 27, 1964–March 10, 1964	SO <sub>2</sub> —0.7 ppm COH—5	300 deaths recorded compared to an average of 260

<sup>a</sup> Cold temperatures (<20°F [-6.7°C]) and an outbreak of influenza may have contributed to the mortality rate during this period

est. Complaints soared during the heating season of October through March, when coal usage climbed and temperature inversions were more common, but declined sharply throughout the rest of the year. Intense lobbying of the mayor's office and city council by real estate and business and industry associations also stalled all efforts at control.

The October 1948 Donora, Pennsylvania, air pollution disaster changed the course of air pollution control. It clearly established the connection between air quality and public health in the minds of the American public including people in New York City. With some 20 people killed and more than a third of the town sickened, the Donora incident pushed air pollution control to the forefront of the political agenda. As a result, in February 1949, New York City had established a well-funded Smoke Control Board. By early August 1949, the board's 10 inspectors were trying to respond to more than 3,000 smoke complaints, most related to apartment building incinerators and boilers. Two of the more notorious smoke sources, Consolidated Edison Company (Con Ed) and the city's own Board of Transportation, refused to comply with Smoke Control Board inspection findings or even pay the fines levied against them.

Con Ed, the country's second largest utility company at the time, burned about half the soft coal in the region, and its Ravenswood and Hell's Gate generating stations were discharging more smoke than thousands of apartment buildings combined. The Board of Transportation operated its own coal-fired electrical generating stations to power the city subways, as well as operating thousands of old diesel-fueled buses. Requiring these facilities to be upgraded would cost millions of dollars and result in utility rate or fare increases. Similarly, forcing apart-

ment and commercial building owners to improve or replace antiquated incinerators or to switch to cleaner-burning natural gas would increase rents or even result in hated tax increases.

Faced with these and other political pressures, the Smoke Control Board, and its successor organization, Department of Air Pollution Control, began a 20-year program of community education combined with selective enforcement that attempted to cajole and pressure industry and the public into voluntary compliance with smoke abatement regulations. It proved to be only moderately successful. The city's air pollution control efforts ground to a halt, as both industries and real estate interests combined repeatedly to derail meaningful regulatory changes that would get at the heart of the problem, namely, the widespread use of inexpensive, dirty coal and the uncontrolled burning of municipal refuse.

By January 1967, New York City had the highest atmospheric sulfur dioxide concentrations in the United States. By that August, the federal government declared New York City's air to be the worst in the nation, with dangerously high levels of not only sulfur dioxide, but also carbon monoxide and particulate. One study predicted that the rate of pollution would make New York City "uninhabitable within a decade," and that residents might be required to live in domes or wear air-purifying respirators. These were not tongue-in-cheek suggestions, but dire warnings from respected government scientists. Adding to New York City's air pollution woes was the prevailing westerly breeze. Long an ally in helping to push particulate and sulfur dioxides out to sea, it now carried in smoke from heavily industrialized parts of northern New Jersey. The oil, chemical, and metal processing industries in Hudson, Bergen, and Essex Counties, as well as more

traditional sources of electrical generation and trash incineration, generated significant air pollution that was swept into the city. State and regional efforts to control pollution in New Jersey were even less effective than in New York, largely because of threats by many industries that they would leave the state if forced to implement expensive air pollution control programs. As a result, by 1965 an article in *Time* magazine described New Jersey's air as "hopelessly polluted."

Several half-hearted attempts were made by several states to organize and deal with air pollution on a regional level. For example, in 1967, Pennsylvania, New York, and New Jersey formed the Mid-Atlantic State Air Pollution Control Commission to establish and enforce air quality standards for all major pollution sources, but the commission never became operational, as a result of political squabbling among various state appointees. It had become painfully obvious that the economic and political pressures associated with forcing real change on urban coal usage, industrial emissions, and municipal trash incineration could not be overcome on a local level. By the mid-1960s, the federal government somewhat reluctantly stepped in to do what neither New York City nor many of the major cities around the country except, perhaps, Los Angeles was able to do: It sought to establish and enforce regulations that would help clear the nation's air. In 1970, shortly after the first Earth Day, the U.S. Congress passed the Clean Air Act Amendments, which gave the EPA primary responsibility for the control of air pollution.

Today, the air quality in New York City is much improved compared to that of the 1950s and 1960s. Air monitoring data for 2010 indicate that New York City meets federal National Air Quality Standards for carbon monoxide, nitrogen dioxide, sulfur oxides, and particulates. The city still does not regularly meet air quality standards for either ozone or, more recently, promulgated fine particulate (particulate matter with a diameter of 2.5 microns or less [PM 2.5]) standards. As improvements in mass transit and air pollution control technologies are made and as the regional economy continues to shift from industrial sector to a service base, within the next few years, New York City and its surrounding metropolitan region may soon have the best air quality of any large city in the nation.

See also AIR POLLUTION; CARBON MONOXIDE; DONORA KILLER FOG; LONDON "KILLER FOG"; LOS ANGELES AIR QUALITY LEGISLATION; MEUSE VALLEY DISASTER; OZONE; PARTICULATE; SULFUR DIOXIDE; TEMPERATURE INVERSION.

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**nickel** Nickel is a naturally occurring inorganic element that is categorized as one of the heavy metals. It is a group 10 metallic element and a transition metal and one of only five elements with ferromagnetic properties. It is the 24th most common element in the crust and believed to constitute more than 6 percent of the Earth's core, where it is most abundant. It occurs naturally in most rocks and soils and is emitted from volcanoes, as well as being a primary constituent of meteorites and ocean floor nodules. Human usage requires mining of nickel ore from either hard-rock sources, where minerals, such as aspentlandite and garnierite, are sought, or deeply weathered areas, where laterites are mined for soft minerals such as nickel-bearing limonite. The nickel ore is then either refined into pure metallic nickel or combined with other elements to produce nickel compounds. The compounds include nickel oxides and hydroxides, nickel sulfides, nickel salts, nickel carbonate, nickel carbonyl, and nickelocene, all with different properties and different uses. It has oxidation states of 0, +1, +2, +3, +4, and possibly +6. It is also considered by many to be a necessary human nutrient in very small quantities. In addition to its numerous beneficial industrial uses, nickel is among the more dangerous pollutants. It has been identified in 882 of the first 1,662 U.S. Environmental Protec-

tion Agency (EPA)–designated Superfund sites on the National Priority List. As the result of this wide distribution combined with the threat to public health, nickel was rated the number 51 worst environmental threat of the 275 top pollutants on the 2007 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USES, AND PRODUCTION

There is evidence that nickel has been used by humans for some 5,500 years, largely as an addition to other metals to form alloys, typically to make them stronger, harder, more heat resistant, and less prone to deterioration. The first reported separation of nickel from other compounds occurred in 1751. Depending upon the compound, nickel is currently or recently used mainly for metallurgy and particularly in alloys such as stainless steel, as a chemical catalyst, in electroplating, in coins and jewelry, in nickel-cadmium and other long-life batteries, and in coloring glass. In 2002, 42 percent of nickel was used in stainless steel and iron alloy production, and 38 percent was used in nonferrous alloys and superalloys (mostly copper and silver), or approximately 80 percent of the total use. Of the remaining 20 percent, 14 percent was used in electroplating and 6 percent for all other uses. The ultimate uses of nickel in 2003 were 32 percent in transportation, 13 percent in the chemical industry, 10 percent in electrical equipment, 9 percent in construction, 8 percent in fabricated metal products, 7 percent in household uses, 6 percent in petroleum refining, 6 percent in machinery, and 9 percent in various other uses. Virtually all metallic nickel is used for metallurgy and electroplating, and the nickel compounds serve many of the other applications. Nickel oxide is used in alloys and steel but also in electronics, in fuel cell electrodes, in coloring of glass and ceramic, in nickel catalysts, and in manufacture of nickel salts. Nickel hydroxide is used in long-life, rechargeable batteries. Nickel sulfides are used as petroleum refining catalysts and some batteries. Nickel salts include nickel acetate and nickel chloride and are used in dyes, in electroplating, as catalysts, and in industrial gas masks. Nickel carbonate is used as a chemical intermediate, in pigments and dyes, in electroplating, and as a catalyst to remove contaminants from water. Nickel carbonyl is used to make high-purity nickel and in semiconductors, and nickelocene is used as a catalyst.

Nickel is primarily produced by Russia at 354,000 tons (322,000 metric tons) per year, Canada at 276,000 tons (258,000 metric tons) per year, Australia at 198,000 tons (180,000 metric tons) per year, and Indonesia at 159,000 tons (145,000 metric tons) per year, using 2007 statistics, although New

Caledonia, Brazil, and Cuba are also major producers. The largest single mine is in Sudbury, Ontario, which has traditionally produced about 30 percent of the world's supply. The United States has sizable deposits in Minnesota and had a steady production rate of 22 million–31 million pounds (10–14 million kg) per year from the mid-1950s through 1980. After 1980, mining declined significantly, and secondary recovery and recycling increased dramatically. Between 1980 and 1990, 55–83 million pounds (25–37.7 million kg) per year was produced from recycling, while primary production declined from 37 million pounds (16.8 million kg) in 1980 to 14 million pounds (6.4 million kg) in 1990. The last U.S. nickel mine closed in 1986, reopened in 1989, and closed again in 1998. Secondary nickel production was about 198–320 million pounds (90–145.5 million kg) per year between 1998 and 2002. Imports of nickel between 1970 and 2002 range between 220 million pounds (100 million kg) and 375 million pounds (170.5 million kg), with a generally increasing trend. In 2007, the United States imported 154,000 tons (140,000 metric tons) and consumed 254,000 tons (231,000 metric tons). The demand for nickel in the United States for stainless steel, nickel superalloys for aircraft and spacecraft, and rechargeable batteries is expected to continue to increase.

### ENVIRONMENTAL RELEASE AND FATE

Most Americans are exposed to small quantities of nickel, because it is widely distributed in air, water, food, and certain consumer products. In addition to natural sources, nickel is released to the environment during mining and refining operations and by the industries that produce nickel, nickel compounds, and nickel alloys or that use nickel and nickel products for manufacturing. It is also released by oil- and coal-burning power plants and incinerators. Nickel can enter the environment from smokestack emissions, industrial wastewater release, and dumping. Nickel entering the atmosphere may settle to the ground directly as fallout, be washed to the ground by precipitation, or attach itself to other particles and then settle to the ground. The duration of this process ranges from immediate to as much as several months. Most nickel is solid with some liquid, but nickel carbonyl can evaporate into an unstable vapor that breaks down quickly. In 1977–82, the concentration of nickel in urban air in the United States was 7–12 nanograms per cubic meter, but thanks to environmental efforts, it was reduced to an average of 2.2 nanograms per cubic meter by 1996. In soils, nickel and nickel compounds tend to bind tightly

to particles that contain iron or manganese and are relatively immobile. They average 4–80 parts per million (ppm) in soil but have been found as high as 9,000 ppm near smelters. Besides some nickel salts, virtually all nickel and nickel compounds are insoluble in water, but metallic nickel, nickel oxides and hydroxides, nickel carbonate, and nickel carbonyl are soluble in certain acids. In conditions of acidic soils, they may become mobile and enter the groundwater system. Nickel in wastewater typically attaches to particles and settles into the sediment. In most surface water systems, nickel averages less than 10 parts per billion (ppb), and in drinking water it ranges from 2 to 4.3 ppb in the United States. It is estimated that 27 million pounds (12.3 million kg) of nickel was released into the environment between 1987 and 1993. The states with the largest releases are, in order, Oregon, Arizona, Idaho, Indiana, Pennsylvania, Arizona, Texas, Maryland, California, and Georgia.

### TOXICOLOGY AND HEALTH EFFECTS FROM EXPOSURE

Nickel and nickel compound exposure produces numerous adverse health effects. The most common health effect in humans is allergic reaction. About 10–20 percent of people are sensitive to nickel and develop skin rashes, dermatitis, and, less commonly, asthma attacks. People may develop sensitivity through chronic long-term exposure. Acute short-term exposure may produce headache, nausea, respiratory problems, kidney damage, increased red blood cells, and death. Soluble nickel compounds are more toxic than insoluble compounds, and nickel carbonyl is extremely toxic through inhalation by producing carbon monoxide gas. Long-term chronic exposure has produced chronic bronchitis; reduced lung function; kidney, liver, and blood disorders; immune system damage; possible reproductive effects; and cancer. Nickel compounds are classified as known human carcinogens (group A), and metallic nickel is classified as reasonably anticipated to be a human carcinogen (group B2). It has been shown that human exposure to nickel compounds increases lung and nasal cancer. Cigarette smoking has a multiplicative effect. It has also been shown that exposure to both nickel and nickel compounds can cause cancerous growths in numerous sites and numerous species of laboratory animals. These include lung, kidney, liver, pulmonary, and pituitary cancers in exposed animals and kidney, liver, and spleen cancer in their offspring. Cancers also developed at every site of injection of nickel compounds. Nickel exposure may also cause genetic damage. Human and

rodent cell cultures exposed to nickel compounds showed deoxyribonucleic acid (DNA) strand breaks, mutations, chromosomal damage, cell transformation, and disrupted DNA.

### REGULATIONS ON HUMAN EXPOSURE

Federal regulatory agencies limit exposure to nickel and nickel compounds. The USEPA limits the amount of nickel in drinking water to 0.1 milligram per liter and requires the reporting of environmental releases of 10 pounds (4.5 kg) or more of nickel carbonyl, nickel cyanide, and nickel hydroxide and 100 pounds (45.5 kg) or more of metallic nickel and all other nickel compounds. The Occupational Safety and Health Administration (OSHA) lists a maximal permissible exposure limit (PEL) of 0.007 milligram per cubic meter of air for nickel carbonyl and 1 milligram per cubic meter of air for metallic nickel and all other nickel compounds. The National Institute of Occupational Safety and Health (NIOSH) has set a recommended exposure limit (REL) of 0.001 ppm for nickel carbonyl and 0.015 milligram per cubic meter of air for metallic nickel and all other nickel compounds. Their immediately dangerous to life and health (IDLH) limit is 2 ppm of nickel carbonyl and 10 milligrams per cubic meter of air for metallic nickel and all other nickel compounds. NIOSH estimates that some 507,681 workers were exposed to nickel and nickel compounds from 1981 to 1983.

See also CARBON MONOXIDE; INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; VOLCANOES.

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### **Norilsk mine and smelter** *Norilsk, Siberia, Russia (1950–present)* *Air and Water Pollution*

Norilsk is a city located just above the Arctic Circle in Siberia, Russia. In winter, temperatures can reach  $-76^{\circ}\text{F}$  ( $-60^{\circ}\text{C}$ ), and yet some 130,000 residents live there. The reason that it is so populated is that Norilsk was built to exploit some of the richest deposits of nickel, copper, palladium, and platinum in the world. The rocks in the area are 250-million-year-old lava flows, collectively called the Siberian Traps. These lavas were rich in sulfur, which combined with nickel, copper, and other metallic elements to form concentrated deposits of pentlandite ( $[(\text{Fe}, \text{Ni})_9\text{S}_8]$ ), chalcopyrite ( $\text{CuFeS}_2$ ), and other ore-bearing minerals. Estimated reserves for these valuable industrial minerals are almost 2 billion tons (1.8 billion metric tons). Ores are removed from underground workings that extend more than 3,900 feet (1,200 m) belowground. The presence of these deposits had been known for many years, but large-scale mining operations did not begin until around 1935, just before the start of World War II. Norilsk was developed and settled in the 1920s and 1930s, primarily by political prisoners and slave laborers exiled to Siberia from other parts of the Soviet Union, although a substantial number of volunteers also moved north to seek employment in the mines and metal processing plants. The city quickly became the regional center for the refining and smelting of ore removed from the surrounding mines. A rail line was extended southward to ports on the Yenisei River, where, during the summer, refined metal and processed ore were transported to the rest of Russia by sea.

For the next 50 years, the Norilsk Metallurgical Combine, a government-owned and operated company, ruthlessly extracted and refined copper, nickel, platinum, and other metallic ores from around Norilsk, without regard to either the environment or the health of its residents. When the Soviet Union broke up in 1995, the Norilsk Metallurgical Combine was privatized through purchase from the government by political insiders for \$150

million and renamed the Mining and Metallurgical Company Norilsk Nickel, or more simply Norilsk Nickel. The new company also maintained its policies of environmental indifference. The company, one of the world's largest miners, generates more than 4 percent of Russia's exports. It is the world's largest producer of nickel and palladium and has major interests in other gold, cobalt, and platinum operations.

The need to attract the \$1 billion of outside investment essential to modernize the aging infrastructure, as well as to meet European Union environmental standards, is forcing mining company and city officials to address three basic challenges to the region's survival: the rehabilitation of the environment, the healing of its citizenry, and the sustainability of its economy.

### **EMISSION OF POLLUTANTS**

After the ore has been removed from the ground and separated from the gangue, or nontarget, minerals, the copper and nickel must be separated from the other elements in the ore minerals. This is done by first calcining, or cooking, and then smelting the ore. The ore is heated in huge vats with other rocks or minerals until everything is molten. There chemical reactions take place in which the elements other than copper or nickel present in the ore minerals are removed into other compounds. The heavier metals settle to the bottom, where they are collected. The lighter compounds float to the top of the molten mass and are skimmed off as slag and discarded. Smelting is energy intensive, but fortunately coal is abundant near Norilsk, and the smelters can be fired using this cheap, plentiful fuel. The problem is that the by-products of both smelting and mining have a high environmental price. During smelting, sulfur in the ore combines with oxygen in the atmosphere to form sulfur dioxide and other sulfur compounds that are released to the atmosphere as vapors. Metals are also released to the atmosphere in this process. Once in the air, the sulfur compounds mix with water vapor to create acid rain. More sulfur, as well as particulate and other dangerous elements such as mercury, is released during the burning of the coal used to heat the ore and power the mills and furnaces. Finally, slag and unprocessed waste rock are dumped in large uncontrolled piles or settling ponds, where they leach metals into soil, surface water, and groundwater. A roughly 25-mile (40-km) area around Norilsk is ecologically dead. All the trees and other vegetation have

(opposite page) Nickel refinery in Norilsk, Russia, dumps tons of sulfur dioxin into the atmosphere every year. (Oleg Nikishin/Getty Images)





been killed by acid rain, and the landscape is scarred by large open pits and piles of waste rock and debris. In some places the upper few feet of soil is so heavily contaminated by atmospheric fallout of nickel and copper that it is economical to mine.

Almost 15 percent of all the industrial pollution in Russia is produced by Norilsk Nickel, with its main Nadezhda Metallurgical facility emitting more than 2 million tons (1.8 million metric tons) of sulfur dioxide into the atmosphere every year since 1950. For comparison, sulfur dioxide emission from all industrial and commercial activities within the entire United States, including electrical generation, is about 15 million tons (13.6 million metric tons) per year. The smelters in Norilsk are arguably the major source of air pollution on the planet. The sulfur and dust stain the snow yellow and black, and the air often tastes sour. Residents have nicknamed the city “Frozen Hell” or “Hell with a Lid On.”

In addition to air pollution, wastewater used in ore processing and metal finishing is discharged without treatment into local watercourses and has resulted in the contamination of more than 60 miles (100 km) of streams and rivers. Although records are difficult to obtain and verify, some environmental advocacy groups have estimated that more than 500 million gallons (1,893 million L) of unprocessed industrial sewage is discharged every year from Norilsk smelters and mines into the rivers and streams of the sensitive Siberian ecology.

There are signs that environmental controls are being slowly implemented at Norilsk. Since 1984, the total amount of air pollution has started to decline very slowly, although levels are still thousands of times above the standards of most Western countries. Plant managers have sought and received outside advice on controlling air pollution, particularly from a Finnish mining and mineral company named Outokumpu Oy. Although severely damaged, the local ecology can recover over time, once the sources of pollution have ended or are under control.

### **PUBLIC HEALTH EFFECTS FROM EXPOSURE**

The environmental consequences of mining and metal processing in Norilsk are highly visible, but the impacts of the operations on the health of its residents are less apparent. Government public health data are not readily available, but even Norilsk Nickel officials admit that only about 4 percent of all adults in the city are “healthy.” Children are particularly affected by the severe air pollution, with skin rashes and respiratory problems, particularly asthma. The air is so polluted that children must be kept indoors 90 days per year.

Company workers can retire at 45, but few live long enough to collect much of a pension. Some published studies have found that living in Norilsk will lower an average person’s life span by 10 years. Although many factors contribute to the poor state of public health in Norilsk, including rampant alcoholism, little to no exercise, and harmful dietary habits, there seems no doubt that the poor quality of the air, water, and environment in general is a significant contributor to the general ill health of the population.

### **ECONOMIC PRESSURES ON MINING**

After the last forced labor camps and gulags closed in the 1970s, many of Norilsk’s current residents were lured to the city by promises of higher salaries, free vacations, and early retirement. Wages in Norilsk are generous by Russian standards, up to \$700 per month, compared to a national average of around \$300 per month. Few workers, however, can afford to leave. The isolation, expense of relocation, difficulty in obtaining housing, and inability to find equivalent employment in other parts of Russia all combine to maintain a captive workforce.

After the collapse of the Soviet Union and the transition to a market-driven economy, the guaranteed employment and pensions the residents of Norilsk learned to expect began to disappear. To remain competitive, the labor force was slashed by almost half (from 100,000 to 60,000), and there are plans to relocate more than 100,000 people living in Norilsk to other parts of Russia. The city simply cannot sustain itself at its current population level. Without major subsidies from the Russian government, it is too expensive to operate the city, and the cost of importing food and other supplies is too high to be economically viable.

One measurable sign of the economic hardships that Norilsk residents are facing is seen in its animal control problem. Attacks on people by stray dogs have become commonplace. As economic conditions changed, many people could no longer afford to keep their pets. As a result, they were abandoned. The number of abandoned and stray dogs in Norilsk has increased significantly, and they are becoming more and more aggressive, forming packs that regularly attack people.

Norilsk is typical of many such Russian towns and communities. A 2000 government-sponsored environmental survey identified 120 cities in Russia that have air quality up to five times worse than acceptable health levels. Even with a major infusion of financial and technical resources from outside the country, Russian environmental quality is not likely to improve over the foreseeable future, as long as

the means of production are driven solely by market factors and remain unchecked by an immature and mostly ineffective regulatory culture.

*See also* AIR POLLUTION; MERCURY; NICKEL; PARTICULATE; SULFUR DIOXIDE.

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**Nowruz Oil Field Persian Gulf, Iran (1981–1988)** *Water Pollution* The Middle East holds about two-thirds of the planet's oil and gas reserves. It is for this reason that it has become so hotly contested over the last quarter of the 20th century and entire 21st century. At some point in the future, historians may refer to the multitude of military conflicts that have erupted there as "the energy wars." Direct attacks on oil production facilities are common in conflicts, as is the disruption of supplies. The largest environmental discharge of oil ever in history occurred in the 1990 Desert Storm conflict, in which retreating Iraqi military forces blew up more than 80 percent of the wellheads in Kuwait's oil fields. The area may never recover ecologically from this disaster. Nowruz is nowhere near as immense as this, but it still played an important role as a strategic piece in the Middle East conflicts.

### BACKGROUND

Some 400 million years ago, as sea level rose, a broad stable platform formed over the Middle East

region. The area changed over time to include a thick salt layer, as well as the deposition of sands, shale, and limestone at various times. Later, these strata were folded, faulted, and intruded by salt domes that accumulated vast quantities of hydrocarbons. Within the Persian Gulf, the reservoir rocks that contain the oil and gas are often in patterns of closely spaced, interconnected fractures in limestone or shale or even in sandstones and coarse-grained sedimentary rocks closer to the surface. The fields are most commonly in broad anticlines and salt domes that contain enormous reserves.

Just after the turn of the 20th century, the first commercial quantities of oil were discovered in Iran. By 1911, the British-owned Anglo-Persian Oil Company (APOC) had developed fields and were shipping the oil by tankers to Europe. After World War I ended, oil was found in Iraq, and by the early 1930s, Standard Oil Company of California (SoCal) was producing oil from fields in Bahrain and Saudi Arabia. By the 1950s, tiny Kuwait had emerged as the region's biggest oil producer, in large part as a result of a government that cooperated enthusiastically with both foreign technical and financial experts. Oman, Qatar, and Abu Dhabi became very active exporters of oil by the early 1960s. By the 1970s, many Persian Gulf countries had taken over active management of the companies producing oil within their borders, and by the 1990s most of these once foreign-controlled corporations were wholly government owned.

Of the Persian Gulf countries, Iran's economy in particular relies extensively on revenues from the export of oil. Western experts estimated that approximately 80 percent of Iran's export earnings are oil related and that oil revenues account for about 50 percent of this country's annual operating budget. In 2004, Iran's oil export revenues were estimated at \$32 billion. By 2005, they were more than \$45 billion and grew to almost \$50 billion in 2006. With this much money at stake, money needed to provide for its people, many of whom are desperately poor, it is no wonder that Iran named one of its most productive oil fields, lying just 40 miles (64 km) off of its coastline, Nowruz.

In Iran, Nowruz is one of the most widely celebrated nonreligious, or secular, holidays. It is the first day of spring or vernal equinox and the beginning of the traditional Iranian New Year. Usually the celebration, also called the Eid Festival, takes place around March 21. Many other countries in addition to Iran celebrate Nowruz, or the "rebirth of nature," including peoples in northern Iraq, Turkey, Afghanistan, and several countries of Central Asia.



### THE POLLUTION

In the early 1980s, a series of pollution events focused the attention of the Arab world on the Nowruz oil field. Iran and its neighbor Iraq went to war in September 1980 because of a long-standing dispute over the control of a key river, the Shatt al Arab. This 120-mile- (193-km-) long tidal stream, formed by the confluence of the Tigris and Euphrates, empties into the Persian Gulf and provides key access to it. It also forms a portion of the boundary between these two countries.

The problems at Nowruz began in 1981, when an out-of-control tanker collided with one of the oil platforms that were actively extracting oil. A well that was damaged beyond easy repair in the accident was successfully capped. Two years later, on February 4, 1983, the platform that the wellhead was attached to began tilting at a precipitous angle. Buffeted by high winds and strong waves, combined with unnoticed corrosion, the riser pipe eventually collapsed into the wellhead. The riser is the part of the pipe that extends above the seafloor and is attached to the wellhead, the point where the borehole enters the seafloor. This collapse began to release approximately 1,500 barrels of oil per day

(almost 60,000 gallons [228,000 L]), and it had to be sealed quickly to prevent a major environmental catastrophe.

When American well-capping experts hired by Iran to seal the blowout asked Iraq for safe passage to the platform, Iraq responded by having its helicopter gunships attack seven other Iranian wells in the same area. Although safety valves automatically shut down four of the damaged wells, the other three began leaking oil into the Persian Gulf at a rate of about 30,000 barrels (1,200,000 gallons, or 4,560,000 L) per day. The resulting slick that formed near the wellhead caught fire, and the oil bubbling to the surface eventually spread to cover 9,000 square miles (23,040 km<sup>2</sup>), or almost 10 percent of the Persian Gulf's open water surface area. Approximately 700,000 barrels (28 million gallons, or 106 million L) of oil spilled into the gulf from these intentionally damaged wells. By mid-May 1983, between 4,000 and 10,000 barrels (160,000–400,000 gallons, or 608,000–1.52 million L) of oil per day was still being released.

As the oil spread, it began to threaten hydrocarbon extraction and recovery operations at not only other platforms and fields, but also other parts of the



Dugong in Lamen Bay, Epi Island, Vanuatu (Mike Parry/Minden Pictures)

industrial and commercial infrastructure that many countries had built up around the waters of the Persian Gulf. These facilities included desalination plants; cooling water intakes for power plants, ports, and harbors; as well as fisheries and habitat for both commercial and indigenous species of plants and animals. The entire population of Persian Gulf sea cows, or dugongs (*Dugong dugon*), was wiped out. These 11-foot- (3.4-m-) long, 2,000-pound (909-kg) creatures, similar to Florida's manatees, use their pointed flippers to "walk" along the seabed as they feed on sea grass, algae that grow in shallow marine environments such as bays, channels, and inshore islands. Although inhibited by the ongoing hostilities from making complete studies, scientists also estimated that large numbers of dolphins, turtles, sea snakes, and birds were killed as the massive slick began to wash ashore on beaches along the gulf. The Nowruz field oil is a "heavy" crude oil, with an American Petroleum Industry (API) gravity of 22. Although information on how the oil behaved once released into the gulf is not available, an estimated 60 percent is thought to have sunk to the seafloor as tarballs, after sand carried by high winds mixed with the oil.

The Iranians successfully shut off the flow of oil from the initial blowout on September 18, 1983. Eleven people died during the operation. In May 1985, the United Nations negotiated a fragile cease-fire between Iraq and Iran that held long enough to allow the fire to be extinguished and three other Nowruz wells to be capped. Nine workers were killed during those operations. The wells leaked more than 30 million gallons (114 million L) of oil into the Persian Gulf over a period of more than two years. The cease-fire did not hold long, and on August 15, 1985, Iraq again attacked the Nowruz oil field. Iraq also launched an air assault, the first of more than 40, on Kharg Island, Iran's main oil export terminal.

Kharg Island is a small island (about 10 square miles, or 26 km<sup>2</sup>) in the northern Persian Gulf. Despite its diminutive size, this island plays a large strategic role in the development of oil resources in the northern gulf. About 16 miles (25.6 km) off the Iranian coast, Kharg Island extends Iran's claim to oil reserves farther into the gulf oil fields. More importantly, Kharg Island has been developed (initially by Amoco in a joint venture with Iran's National Petrochemical Company [NPC]) into one of the largest oil storage and processing terminals in the gulf. Now operated solely by NPC, the Kharg Island terminal processes, stores, and exports more than 90 percent of Iran's oil. Oil from offshore platforms is pumped via pipeline into the

terminal's storage tanks, where it is processed to remove methane, water, and salt. The oil then is loaded onto tankers for shipment through the Straits of Hormuz for delivery in Europe, the Americas, and Asia. The Kharg Island complex was rebuilt after the Iran-Iraq War, which ended on August 20, 1988. It was expanded in 1994 to increase its capacity by more than 40 percent. The dispute over the Shatt al Arab was finally settled when a coalition of international military forces, led by U.S. and British troops, invaded Iraq in 2003.

See also BEACHES; CONTINENTAL SHELF; GULF WAR OIL SPILLS; OIL SPILLS.

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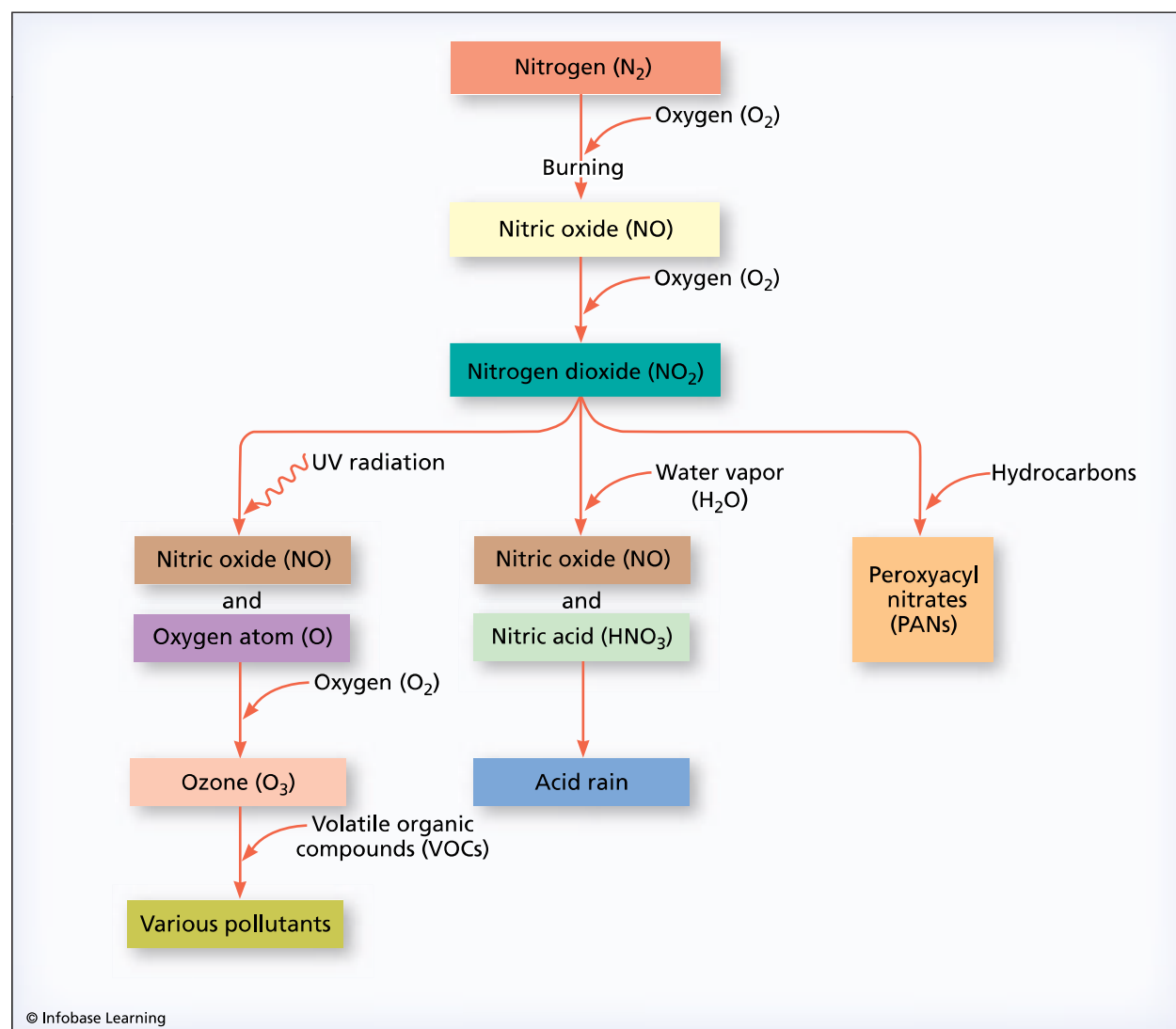
**NO<sub>x</sub> (oxides of nitrogen)** The U.S. Environmental Protection Agency (EPA) began tracking emissions of the six designated principal air pollutants in 1970. By 1998, levels of five of the six, carbon monoxide, lead, particulate matter, sulfur dioxide, and volatile organic compounds, had all been substantially reduced, but that of NO<sub>x</sub> had actually increased 10 percent over the period. Considering that NO<sub>x</sub> is a direct cause of ground-level ozone (smog), acid rain, surface water quality deterioration, global warming, decreased visibility, toxic chemical production, and the production of particulate matter, it is a great threat to the environment, as well as human health. Since 1998, efforts have been stepped up to reduce NO<sub>x</sub>. There are several oxides of nitrogen (components of NO<sub>x</sub>) including nitric oxide (NO, or nitrogen I oxide), nitrogen dioxide (NO<sub>2</sub>), dinitrogen monoxide (N<sub>2</sub>O, or nitrous oxide), dinitrogen trioxide (N<sub>2</sub>O<sub>3</sub>, or nitrogen III oxide), dinitrogen tetroxide (N<sub>2</sub>O<sub>4</sub>), and dinitrogen pentoxide (N<sub>2</sub>O<sub>5</sub>). Nitric oxide is undesirable, and nitrogen dioxide and dinitrogen monoxide are toxic; the other three are unstable. NO<sub>x</sub> is so widespread and affects so many people in so many ways that it is one of the most hazardous pollutants.

Nitrogen dioxide has been identified in nine of the first 1,585 EPA-designated Superfund sites on the National Priority List, and nitric oxide has been identified in six. On the 2007 CERCLA Priority List of Hazardous Substances, nitrite is ranked as the 212th worst pollutant, and nitrate is 216th of 275 substances listed.

### PROPERTIES AND SOURCES

Nitrogen dioxide is a colorless to brownish liquid with a sharp harsh odor at room temperature but a red-brown gas above 70°F (21°C). Nitric oxide is a colorless, sharp, but sweet-smelling gas. There was about 58 million tons (53 million metric tons) of NO<sub>x</sub> released into the atmosphere by human activity on a global basis in 1970. The total natural and

anthropogenic releases of NO<sub>x</sub> were 1.2 billion tons (1.1 billion metric tons), an indication that natural sources predominate by nearly 95 percent. Natural sources include bacterial action on soil, volcanic eruptions, forest fires, and lightning. Natural NO<sub>x</sub> is spread evenly throughout the atmosphere, whereas anthropogenic NO<sub>x</sub> is concentrated at the sources, building to dangerous levels on a local scale. The anthropogenic sources of NO<sub>x</sub> emissions in the United States in 2003 were 55 percent from motor vehicles; 22 percent from utilities, including power generation; 22 percent from industrial, residential, and commercial sources; and 1 percent from all other sources. The commercial sources include arc welding, electroplating, engraving, dynamite blasting, and the production of numerous chemicals, dyes, lacquers, rocket fuel, trinitrotoluene (TNT),



**Schematic diagram showing the steps in producing NO<sub>2</sub> from car exhaust and the three main hazards in the atmosphere that it leads to: ozone, acid rain precipitation, and nitrates**

gun cotton, and dynamite. Nitrous oxide is also used for dental anesthesia (laughing gas). Scientific studies in 2005 showed that up to 9.7 million tons (8.9 million metric tons), or 22 percent of NO<sub>x</sub>, is directly emitted to the atmosphere from nitrogen-fertilized (ammonium and nitrate) farmland, a total much higher than previous estimates. NO<sub>x</sub> is also produced in tobacco smoke, where typical concentrations are 145–230 parts per million (ppm), well into toxic levels.

It is estimated that 25 percent of NO<sub>x</sub> emissions were from coal-fired power plants by 2006. NO<sub>x</sub> is produced from coal by several processes including (1) fuel NO<sub>x</sub> by direct release through burning; (2) thermal NO<sub>x</sub> by the splitting of stable nitrogen atoms by high temperatures, which then react with oxygen; (3) prompt NO<sub>x</sub> from the reaction of atmospheric nitrogen with radicals; and (4) feed NO<sub>x</sub> from cement production, the last two of which are negligible.

### ENVIRONMENTAL INTERACTIONS

NO<sub>x</sub> is primarily a nonpoint source pollutant that is released to the atmosphere. It occurs rarely as a point source pollutant in waste sites. When released to the atmosphere, NO<sub>x</sub> degrades rapidly in air by reacting with other chemicals. Most NO<sub>x</sub> rapidly oxidizes to nitrogen dioxide (half-life of about 50 days depending upon conditions). Nitrogen dioxide reacts with photochemically produced radicals to form nitric acid, which is a major component of acid rain. It also reacts photochemically with volatile organic compounds to form ozone or smog, which accounts for much of the regional haze in urban and even rural areas. The average annual visibility in the Great Smoky Mountains is reduced to 25 percent by fog. Much of this NO<sub>x</sub> is returned to the surface in precipitation as acid rain, which damages vegetation and helps to produce the “dead lakes” of the Adirondack Mountains and other areas. In water bodies where the pH is buffered to near-neutral conditions, the increased nitrogen causes *eutrophication*, or oxygen depletion by algal blooms. Coastal waters are especially susceptible to nitrogen fallout and washout. It is estimated that deposition of air pollution-generated nitrogen accounts for 33 percent of the total nitrogen load in the Albemarle-Pamlico estuary of North Carolina, 27 percent of that in the Chesapeake Bay of Maryland and Virginia, and 15 percent of that in the Long Island Sound, New York.

NO<sub>x</sub> has daily and seasonal trends in urban and suburban areas. There are typically two times of high concentrations during the day, corresponding to morning and evening rush hour. During these

times levels can be twice as high as they are during the lowest periods of the day. The highest concentrations in the atmosphere are typically the winter months of November through February, whereas the lowest months are the summer months of June through August. The reason for this is that NO<sub>x</sub> reacts with volatile organic components to produce ozone if exposed to strong sunlight. The summer reduction corresponds to a sharp increase in ozone, which is also toxic and destructive.

NO<sub>x</sub> additionally contributes to the level of particulate in the atmosphere. Through reactions with water vapor, ammonia, and other compounds, NO<sub>x</sub> helps to form small particles that can cause respiratory system damage. People with asthma, heart disease, emphysema, and other respiratory problems are especially sensitive to particulate. These reactions may also produce toxic chemicals that may damage vegetation and human and animal health if inhaled. NO<sub>x</sub> is also a greenhouse gas and, therefore, contributes to global warming.

If it is released directly into water, a small amount may evaporate, but the majority of the NO<sub>x</sub> will react with the water to form nitric acid. If it is released into the soil, small amounts may evaporate into the air, but the majority will react to form nitric acid. Animals (birds and mammals) experience similar adverse health effects to exposure to NO<sub>x</sub> that humans do, and plants may also be damaged.

### HEALTH EFFECTS FROM EXPOSURE

Exposure to NO<sub>x</sub> can cause numerous adverse health effects. Acute exposure to low levels of NO<sub>x</sub> can irritate the eyes, nose, throat, and lungs and produce coughing, shortness of breath, fatigue, nausea, and vomiting. Within one to two days of no symptoms after the initial exposure and effects, fluid may build up in the lungs from pulmonary edema and may be accompanied by anxiety, mental confusion, lethargy, and loss of consciousness. Exposure to high levels of NO<sub>x</sub> can cause rapid burning, spasms, and swelling of the throat and upper respiratory tract, causing asphyxiation. Rapid buildup of fluid in the lungs may be fatal. It can also interfere with the oxygen-carrying capacity of the blood, causing headache, fatigue, mental confusion, dizziness, and blue color in the skin, especially around the lips. It can even produce serious burns of the skin and eyes (including blindness) and at high concentrations can damage the teeth. Long-term chronic exposure can cause serious respiratory problems including asthma and permanent damage to the lungs, heart, and nervous system. NO<sub>x</sub> has also been shown to be capable



of genetic damage including deoxyribonucleic acid (DNA) damage, mutations, and other aberrations, as well as damaging developing fetuses and decreasing fertility in women.

### REGULATIONS ON HUMAN EXPOSURE

The EPA limits the average annual concentration of nitrogen dioxide in ambient air to 0.053 ppm. The Occupational Safety and Health Administration (OSHA) list a maximal permissible exposure limit (PEL) of 25 ppm for nitric oxide averaged over an eight-hour-day, 40-hour workweek and a limit of 5 ppm of nitrogen dioxide over 15 minutes. The National Institute of Occupational Safety and Health (NIOSH) has set an immediately dangerous to life and health (IDLH) limit of 100 ppm for nitric oxide and 20 ppm for nitrogen dioxide.

In order to reduce NOx emissions from coal-fired plants, new clean-burn technologies are required by the Department of Energy. Staged-combustion low-NOx burners have now been installed on 75 percent of plants and reduce NOx emissions by 40–70 percent or to 0.25–0.65 pound of NOx per million British thermal units (BTUs). New Clean Air Act and Clean Air Interstate Rule regulations restrict NOx emissions to 0.15 pound (0.07 kg) per million BTU for the District of Columbia and 22 states: (Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Ohio, Michigan, Wisconsin, Illinois, Indiana, Missouri, Kentucky, West Virginia, Maryland, Delaware, Virginia, North Carolina, Tennessee, South Carolina, Georgia, and Alabama). In order to meet these new regulations, several new technologies have been developed including selective catalytic reduction, a new generation of low-NOx burners, water injection technology, advanced reburning of fuel, and oxygen-enhanced combustion, which can reduce emissions by as much as 80–90 percent. As a result of these efforts, NOx pollution over the eastern United States decreased by about 40 percent between 1999 and 2006. Unfortunately, there are “grandfathered” old coal-burning plants that were not required to meet the stringent guidelines. They emit 10 times as much NOx pollution as the modern plants. Between 1992 and 1998, the amount of electricity produced by these old plants increased by 15.8 percent before the new standards reduced their usage.

The 1997 Kyoto Protocol, which was ratified by 54 countries excluding the United States, which refused, requires a substantial reduction in greenhouse gases including nitrous oxide. Many of the goals of this agreement were required to be satisfied by 2010. This is the second world agreement to

reduce NOx. The first was the 1988 Sofia Protocol to control emissions of NOx or their transboundary fluxes. Most of the 25 participating countries agreed to reduce NOx emissions to 1987 levels and freeze them. In this agreement, the United States volunteered to reduce NOx emissions to 1978 levels.

See also AIR POLLUTION; EUTROPHICATION; NOx EMISSION CONTROL SYSTEMS; OZONE.

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**NOx emission control systems** Nitrogen oxides, or NOx, are formed by three mechanisms. In a combustion chamber such as a furnace or incinerator, molecular nitrogen (N<sub>2</sub>) present in the atmosphere can become thermally bonded to the oxygen in the air being fed into the system for combustion. NOx produced in this way is called thermal NOx, and its formation is dependent upon flame temperature and fuel availability. The higher the temperature and the leaner the air-to-fuel ratio, the more oxygen will be available for reaction with molecular nitrogen in the hot region of the flame. More NOx, therefore, will be produced.

The second way NOx is produced occurs when fossil fuels, including coal, oil, and natural gas, release the nitrogen they contain in their molecules into the atmosphere during combustion. This NOx is called fuel NOx and is associated primarily with coal and heavy oils. As with thermal NOx, the for-

mation of fuel NOx is dependent upon flame temperature and the ratio of combustion air to fuel.

The third way NOx is produced during combustion occurs when nitrogen combines with hydrocarbons in the fuel to create hydrogen cyanide (HCN). The HCN is oxidized to NOx within several microseconds. This NOx is called prompt NOx and is made in significant amounts only in fuel-rich combustion mixtures and is produced by high-speed reactions in the hottest part of the flame. Generally, prompt NOx is a minor part of total NOx production, especially when natural gas is being burned.

### CONTROL OF NOx

The technologies available to control the release of NOx can be divided into two broad categories, source controls and postcombustion controls. Source controls are those that reduce the amount of NOx created in the combustion zones of the furnace as the fuel is being burned. These include low-NOx burners (LNBs) and combustion controls. Postcombustion controls are those that reduce NOx concentrations in the exhaust gas as it exits the stack, vent, or tailpipe. Postcombustion control technologies include selective and nonselective catalytic reduction, conventional reburning, and fuel-lean gas reburn (FLGR).

For the burning of a relatively clean fuel, such as natural gas, which has a low nitrogen and sulfur content, not much NOx is generated. For fuels with higher nitrogen and sulfur content, such as coal and oil, production of NOx can be significant. One way to lower NOx concentrations during fuel burning is to lower flame temperature. This is done by modifying the burner to increase its surface area, creating a larger but lower-temperature fire. These types of low-flame combustion systems are called low-NOx burners, or LNBs.

Combustion control is another method that can be used to reduce NOx concentrations in exhaust gases. This technology involves the use of a series of techniques to manage the combustion process and increase the efficiency of the burner. Staged combustion allows the initial firing to take place in a high-temperature, fuel-rich zone, where more fuel is present than air available to burn it. Combustion is then completed in a lower-temperature, fuel-lean zone, where there is more air than fuel present. If oxygen is not present in sufficient amounts to combust all of the fuel in the fuel-rich, oxygen-deficient zone, formation of NOx is very limited. Combustion in the secondary zone is conducted at lower temperature, reducing the amount of NOx produced. Low-NOx burners also can be used in combination with staged-combustion technology.

In secondary air staging, also called overfire air, a portion of the air for combustion is redirected to above the level where fuel is being added. Doing this allows the unburned materials leaving the main combustion zone to ignite when mixed with this added, overfire air. In a similar process, using flue gas recirculation, the hot gases created by combustion (flue gas) are directed back into the combustion zone, to lower flame temperature and oxygen content, thereby reducing NOx formation.

If one or several of these approaches are combined into a single unit, it is called a NOx burner. These types of systems can reduce NOx generation by as much as 30–50 percent, although they also reduce boiler efficiency, resulting in higher operating costs.

### Example of the University of California

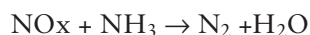
The San Diego Air Pollution Control District (SDAPCD) has some of the toughest emission standards in the United States, and the University of California at San Diego (UCSD) has to comply with these standards just as any business or company does. As part of its physical plant, UCSD operates three 40-year-old boilers that provide steam for heating and other building operations. The emissions from these boilers were having trouble consistently meeting the SDAPCD's 30-parts per million (ppm) NOx discharge limit. Rather than replace or upgrade the boilers, UCSD hired a specialty-engineering firm that converted them to low-NOx operation. The existing burners, initially supplied with the boilers in 1965, were modified with a computerized combustion control system. Although some equipment had to be upgraded, including installing a variable speed drive to manage the combustion air fan better, the new combustion control system resulted in a reading of 16 ppm, the lowest recorded NOx in the SDAPCD. The length of time required to recover the installation cost through reduced operating expenses for the system was a very fast nine months.

### POSTCOMBUSTION NOx REDUCTIONS

It is not always possible to reduce NOx concentrations in stack emissions to the mandated regulatory level only through combustion control and low-NOx burner technologies. To meet levels mandated by the Clean Air Act and other regulations, a postcombustion processing technique has to be applied on the "downstream" side of the burner. Dependent on the emission limits that need to be met, either a selective catalytic reduction (SCR) or selective noncatalytic reduction (SNCR) technology can be used.

Selective catalytic reduction (SCR) chemically treats combustion gases to convert NOx to inert

nitrogen gas or  $N_2$  and water. Before being discharged from a vent or stack, the exhaust gas is passed through a reactor or catalyst bed, usually made with vanadium, titanium, or platinum, where it is mixed with ammonia and air or steam. On the surface of the catalyst, the ammonia reacts with the NOx to form molecular nitrogen ( $N_2$ ) and water as follows:



Typical NOx reduction efficiencies of SCR systems are 75–90 percent. SCR systems, however, are expensive to install and difficult to operate and maintain. The catalytic reaction works best at temperatures of 400–800°F (204–427°C). If the temperature is too low, excess ammonia fumes are discharged. If it is too high, additional NOx is produced. Also, the reactor bed is easily poisoned or contaminated by dust, sulfur, or chlorine compounds, which need to be filtered or treated before exhaust gases are allowed to contact the catalyst.

Catalytic reduction also is used to help lessen NOx concentrations from automobile exhaust. In an automotive catalytic converter, the reduction catalyst is platinum and rhodium. As gasoline is burned, the resulting NOx vapors have contact with the catalyst, which separates the nitrogen molecules from the oxygen molecules. These nitrogen molecules eventually combine to form inert atmospheric-type nitrogen ( $N_2$ ), while the oxygen is released in the form of  $O_2$ .

Selective noncatalytic reduction (SNCR) is a post-combustion process that also involves the injection of a NOx reducing agent, such as ammonia or urea, into the exhaust gas stream. A reducing agent is an element or compound that is used to remove oxygen from another compound. In contrast, oxidizing agents combine or add oxygen to other elements or compounds. The only problem is that SNCR requires high temperatures, 1,400–1,600°F (760–871°C). Under these conditions, the ammonia or urea separates the NOx in the exhaust gases into water and atmospheric nitrogen. SNCR can reduce NOx by 20–60 percent.

Conventional reburning can result in significant levels of NOx removal without the use of chemical reagents or catalysts and, in some cases, without modifying or replacing existing burner equipment. In conventional reburning, natural gas is injected above the primary combustion zone to create a fuel-rich and air-lean zone, where NOx is reduced. Additional overfire air is then introduced above the reburning zone to complete combustion. The objective of conventional reburning is to create a reducing environment within the combustion chamber that

converts NOx formed in the primary combustion zone to molecular nitrogen. Conventional reburning can reduce NOx emissions by 50–70 percent. An added benefit of introducing natural gas into the combustion process is that by substituting or replacing part of the burner's standard fuel with natural gas, less SOx,  $CO_2$ , and particulate (particulate matter with a diameter of 10 microns or less [PM-10]) is created. Conventional reburning can be used as a stand-alone approach to NOx control or in conjunction with other source control or postcombustion processes, such as low-NOx burners.

### FUEL-LEAN GAS REBURN (FLGR)

Fuel-lean gas reburn (FLGR) is a patented NOx control technology in which natural gas is fed into the upper regions of the burner to establish a local air-rich and fuel-lean combustion environment. The natural methane gas forms hydrocarbon radicals that react with the NOx produced during combustion to form HCN, or hydrogen cyanide. This HCN then undergoes a further series of reburning reactions within the locally fuel-rich upper region of the burner, eventually transforming the NOx into elemental nitrogen, or  $N_2$ . Maintaining the correct balance between the injected natural gas and the burner's standard operating fuel of coal, natural gas, or oil is critical to effective NOx removal. If it is done correctly, NOx reductions of 35–45 percent can be achieved.

### Example of Riverbend Unit 7

Riverbend Unit 7, operated by Duke Power, is a 140-megawatt tangentially fired coal-burning utility boiler, which began operations in 1954. Located near Mount Holly, North Carolina, Riverbend Unit 7 is named for a bend in the Catawba River. Duke Power operates almost 30 tangentially fired boilers where pulverized coal and combustion air are introduced through the corners of the boiler in such a way that the mixture intersects the outside of an imaginary circle in the middle of the furnace. Duke Power, one of the more environmentally proactive utilities in the United States, previously installed low-NOx burners on Riverbend Unit 7 to meet acid rain requirements of the 1990 Clean Air Act Amendments. With these modified burners, Riverbend Unit 7 produced 0.40–0.45 pound (0.18–0.2 kg) of NOx emissions per million British thermal units (BTUs) of heat produced. Duke Power recognized that an additional approximately 45 percent reduction in NOx emissions would soon be required by even stricter air quality regulations. They investigated the use of FLGR to determine whether it was a more cost-effective option than either conventional reburning or SNCR.

FLGR proved to be a very cost-effective emission control technology because of the easy access to nearby natural gas supplies. The FLGR system installed and operated at Riverbend Unit 7 resulted in significant NOx reductions, although elevated CO emissions became an issue during early system operations. Once modifications were made to the gas injection system, CO emissions decreased dramatically, and the performance of FLGR improved. If FLGR can be used successfully on all the tangentially fired boilers in Duke Power's generating system, it will allow this utility to attain a 40 percent reduction in NOx emissions and could potentially reduce the utility's capital cost of compliance with air pollution control requirements by approximately \$70 million.

FLGR is an attractive technology, not only for Duke Power but also for many other utilities, because it can be a relatively inexpensive addition to existing combustion systems, without the need for a major overhaul or retrofit. It also is a compatible add-on or supplemental technology with other NOx control systems.

*See also* AIR POLLUTION; CARBON MONOXIDE; NOx; PARTICULATE; SULFUR DIOXIDE.

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**ocean dumping** People have utilized the oceans for food, transportation, and recreation for millions of years. Unfortunately, up until very recently, humans have also used the ocean as a dumping ground. Unlike marine litter or ships' sewage, which are accidentally, randomly, or even, at times, secretively released, ocean dumping is the direct release or discarding of waste materials, usually from a barge or ship, at a specified place on the ocean floor. Over the last century, the United States and other countries have intentionally disposed of a vast amount of unwanted materials at sea. An estimated 25 million tons (22.7 million metric tons) of industrial waste was dumped into the ocean during the 1970s and 1980s alone.

These vast, seemingly limitless expanses of ocean floor, remote from population centers, appeared to be the perfect place to dispose of sewage sludge, scrap metals, mine tailings, radioactive waste, pesticides, and other types of organic compounds. Encouraging this “out-of sight, out of mind” approach to ocean dumping was the lack of scientific information on ecosystems that might be present at the bottom of the sea.

This attitude began to change as deep sea submersibles and other deep ocean exploration techniques began to be developed in the early 1970s. One groundbreaking study, done in 1982 by Woods Hole Oceanographic Institute, identified almost 800 different species of sea life at depths of more than 6,000 feet (1.8 km) off the east coast of New Jersey and Delaware. This high degree of biodiversity increased to the south as water temperatures warmed, and it is thought that there may be more than 10 million different species present on each half-square-mile (1.3 km<sup>2</sup>) of ocean floor, even at

depths greater than 3,000 feet (0.9 km). This study and other research have demonstrated that near-shore ocean floor habitats may be just as ecologically alive and vital as equivalent land-based systems. Just as in sensitive terrestrial habitats, ocean dumping can disrupt these ecosystems and result in significant harm to marine life, ultimately damaging fisheries and other food sources.

### MAJOR POLLUTANTS

Trash, industrial waste, and sewage sludge often contain pesticides or heavy metals such as lead, copper, and cadmium that can be concentrated in sediments and eventually work their way into the food chain. Through bioaccumulation, fish and sea mammals could be poisoned, reducing their ability to reproduce or making them unsuitable for human consumption. Dumping of certain organic wastes lowers the dissolved oxygen level in the water and thereby can kill off clam beds and other shellfish that many commercial fish and people rely on for food. This occurs through *eutrophication*, a biological process in which nitrogen and phosphorus present in waste allow oxygen-depleting bacteria to proliferate. In turn, these organisms create a hypoxic, or oxygen-poor, environment that kills other essential marine life.

Pathogens including bacteria, viruses, and other disease-causing organisms that are disposed of at sea with the waste material have caused fish to be infected with such illnesses as black gill, or bacterial gill disease. This condition is characterized by the growth of filamentous bacteria on the gills and leads to a fusing of the gill filaments. The infection reduces the gill's respiratory efficiency, eventually killing the fish.

## AIR POLLUTION OVER THE OCEAN

There are few experiences as refreshing as standing on the beach in the evening and enjoying the feel of an onshore ocean breeze. Unfortunately, the quality of the air in that breeze is under attack from a variety of both land- and ocean-based air pollution sources. The manufacturing and related commercial activities that support the economies of developed and developing countries place enormous pressures on the natural cleansing and pollution attenuation mechanisms that operate within the oceans. More important, pollution associated with inland industrialization, including its by-products of desertification and soil erosion, is often directly translated to environmental degradation of marine air quality.

### LAND-BASED POLLUTION SOURCES

The release, long-distance transportation, and settling, or deposition, of atmospheric pollutants from both natural and industrial land-based sources have been widely recognized as significant contributors to oceanic and surface water body pollution. This can occur either directly, as winds carry pollutants from their sources far out into the ocean, or indirectly, as rivers and streams flush pollutants into harbors and estuaries. Three processes operate to deposit air pollutants to surface water: gas exchange, dry deposition, and precipitation.

#### 1. Gas Exchange

Semivolatile organic compounds such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), mercury, and certain types of pesticides have the unusual property of being able to exist in the atmosphere in both a particulate (solid) phase and a gas phase. Their low vapor pressure and relatively insoluble nature make them able to evaporate upon release into the environment (e.g., pesticide sprayed onto a field). Once in the atmosphere, semivolatile compounds can travel long distances by cycling between the gaseous and solid states. They are deposited, volatilized, and remobilized as atmospheric conditions change according to season. Once in the ocean or other surface water body, their resistance to natural degradation by bacteria, sunlight, or other biochemical processes allows them to accumulate in the water column or sediments, where they eventually enter the food web, taken up by plants, phytoplankton, or other primary producers.

#### 2. Dry Deposition

This process takes place as particulate matter settles out of the atmosphere directly into the ocean or surface water body. It is a continuous process and under natu-

ral conditions is beneficial, providing a steady stream of mineral-rich dust to microscopic marine plant and animal life far from the shore. If toxic contaminants such as hydrocarbons, lead, or dioxins are attached to the particulate, however, measurable impacts to environmental quality and aquatic life can occur. Pesticides such as dichlorodiphenyltrichloroethane (DDT), chlordane, and toxaphene have been detected at high levels in the blubber of Arctic whales, where such substances have never been applied. More than 1,000 miles (1,609 km) from shore over the Indian Ocean, scientists have measured a 1¼-mile- (2-km-) thick layer of haze that reduces visibility to less than six miles (10 km), similar to many polluted areas on land. This haze consists primarily of soot, sulfates, nitrates, organic particles, fly ash, and mineral dust and presumably emanates from Asia and the Indian subcontinent. The presence of such a dense, widespread layer of pollution so far from land-based sources raises concerns over the effects of reduced sunlight on aquatic organisms and increased rates of radiational cooling from higher rates of reflected sunlight.

#### 3. Wet Deposition/Precipitation

Both gaseous and particulate pollutants can be incorporated into cloud droplets and be flushed into the ocean or surface water by rain, snow, or ice pellets (sleet). They can also be removed from the atmosphere as nonpolluted precipitation falls through and absorbs the contamination. The capture of pollutants by wet deposition is highly dependent upon the solubilities of the materials. More soluble compounds such as SO<sub>x</sub>, nitrobenzene, and acetonitrile are more susceptible than relatively insoluble compounds such as pesticides and PCBs. Airborne dispersion and wet deposition processes ensure that pollutants are not necessarily deposited in the same country where they were released. In 1998, for example, 25 percent of the sulfur oxides deposited on the United Kingdom were from other countries. That same year, 90 percent of the sulfur oxide pollution washed out of the atmosphere in Sweden and Norway blew in from across the Baltic Sea and the Gulf of Bothnia.

### OCEAN ACIDIFICATION

As the amount of carbon dioxide (CO<sub>2</sub>) in the atmosphere rises as a result of the increased burning of coal and other fossil fuels, some of it is taken up by the

*(continues)*

(continued)

terrestrial biosphere (i.e., plants), and the rest settles into the oceans either dissolved in rainwater or as carbonic acid ( $\text{H}_2\text{CO}_3^-$ ), bicarbonate ( $\text{HCO}_3^-$ ), or carbonate ( $\text{CO}_3^{2-}$ ), depending upon temperature, ocean salinity, and several other factors. Ocean absorption of  $\text{CO}_2$  is a critical component of the carbon cycle as it helps to moderate the amount of  $\text{CO}_2$  in the atmosphere and thus the Earth's climate. Excessive amounts of  $\text{CO}_2$  released since the beginning of the Industrial Revolution, however, have started to overwhelm the natural system of atmospheric carbon checks and balances and may be leading to fundamental changes in ocean chemistry. Acidification also has been related to increased amounts of sulfur dioxides, produced by the burning of fossil fuels. Sulfur dioxides combine with rainwater and surface water to form sulfuric acid.

As the oceans absorb more  $\text{CO}_2$ , hydrogen ion ( $\text{H}^+$ ) concentration increases, lowering ocean water pH and raising the level of acidity. Recent studies predict that by 2100, ocean water pH will decrease by up to 1.4 standard units as it struggles to take in the overabundance of carbon dioxide present in the atmosphere. This absorption, termed ocean acidification, will aid in reducing the amount of carbon in the atmosphere. On the other hand, it puts a wide variety of aquatic organisms at risk. Calcium deficiencies have already been documented in fish and other types of marine life. They result in weakened bones and brittle eggs, as well as damaging the ability of gills to absorb oxygen from seawater. Toxic metals present in ocean sediment (aluminum, arsenic, cadmium, and mercury) become more mobile and bioavailable under acidic conditions. Similar effects have been observed in freshwater bodies such as lakes and estuaries.

More importantly, acidification threatens the very foundation of the ocean's food web, namely, corals, coccolithophores, some types of pteropods and foraminifera, as well as many other types of free-floating and benthic life-forms. These organisms have exoskeletons made of calcium carbonate ( $\text{CaCO}_3$ ), which becomes very unstable and more soluble as seawater becomes more acidic. The calcareous phytoplankton and zooplankton most affected by ocean acidification form the base of the marine food web and make up 95 percent of the primary producers in the ocean. Ocean phytoplankton make up approximately 1 percent of the Earth's biomass but are responsible for about half of the photosynthetic activity on the planet. These organisms remove  $\text{CO}_2$  from the atmosphere and release valuable oxygen. Without a healthy and thriving pelagic population, the oceanic food web will col-

lapse and with it so will a major source of sustenance and commerce for the world. The potential for ocean acidification to result in a catastrophic failure of the Earth's oxygen nutrition engines provides a real impetus to expand efforts to improve control and reduce emission of greenhouse gases.

### MARINE ENGINE EXHAUST

Diesel fuel is especially well suited for use in marine vessels. It has low volatility and high flash point ( $150^\circ\text{F}$  [ $65.6^\circ\text{C}$ ] versus  $30^\circ\text{F}$  [ $-1.11^\circ\text{C}$ ] for gasoline), which make it safer to use in the tight confines of a ship's engine room. Diesel engines are more efficient than gasoline engines, burning 20–30 percent less fuel to generate the same amount of horsepower and, as such, are cheaper to operate. Also, given diesel's low autoignition temperature ( $446^\circ\text{F}$  [ $230^\circ\text{C}$ ] compared to  $1,022^\circ\text{F}$  [ $550^\circ\text{C}$ ] for gasoline), the amount of waste heat this type of engine generates is low. As an added benefit, diesel engines can be scaled up to very large sizes and provide the enormous amounts of torque needed to push a ship through the water.

In terms of their exhaust, engines burning diesel fuel produce much less carbon monoxide (CO) than gasoline engines; that is why truckers can leave their engines running overnight while they sleep. Diesel engine exhaust, however, contains large amounts of nitrogen oxides, particulate, and hydrocarbons in the form of soot or unburned carbon particles. The characteristic black smoke given off by diesel engines is caused by insufficiently atomized fuel because injectors are faulty or because more fuel is being injected than can be burned in the motor's combustion cycle, otherwise known as the black smoke limit.

The environmental and public health effects of diesel exhaust can be significant. Particulate matter given off with this type of exhaust contains a high coarse fraction (particulate matter with a diameter of 10 microns or less [ $\text{PM}_{10}$ ]), which has been linked to such respiratory diseases as asthma, emphysema, and possibly cancer. Nitrogen oxides and sulfur oxides, which are also present in diesel emissions, contribute to ocean acidification and may disrupt nutrient cycles by causing local increases in nitrogen concentrations leading to eutrophication. Particulate can also temporarily reduce local visibility and incoming sunlight, thus impacting photosynthetic marine organisms.

On a global basis, marine diesel exhaust makes up about 7 percent of emitted  $\text{NO}_x$  and 4 percent of  $\text{SO}_x$ . In the United States, annual diesel exhaust emissions from container and cruise ships at the 10 busiest ports produce the same amounts of  $\text{NO}_x$  and  $\text{SO}_x$  as more

than 3 million and 18 million cars, respectively. Considering that the amount of maritime shipping is expected to double by 2020, diesel exhaust will contribute significantly to the growing pollutant load in the Earth's atmosphere.

### REGULATIONS ON OCEAN AIR POLLUTION

Fortunately, the global community is taking steps to address this problem of diesel exhaust. In 1997, the UN's International Maritime Organization (IMO) passed Annex VI to the International Convention for the Prevention of Pollution (MARPOL 73/78) from oceangoing vessels. The IMO is an international agency responsible for developing standards for the use of the world's oceans. This includes not only environmental, but also ship operation/safety standards, resource exploitation including fishing and oil exploration, and other ocean-related activities. Once a standard is promulgated, it becomes international law after its ratification by a certain number of member countries. Annex VI, which took full effect in 2005, establishes limits on the sulfur and nitrogen oxide emissions from ship exhaust and totally prohibits the release of ozone-depleting substances. Exceptions are made for emergencies when the integrity of the ship or safety of the crew is at risk. These exceptions mainly apply to the operation of diesel-fired emergency pumps. Annex VI also established the North Sea and Baltic Sea as Special SO<sub>x</sub> Emission Control Areas (SECAS), where only very low-sulfur diesel fuel (1.5 percent or less) can be used.

The maritime shipping industry has taken a multi-phase approach to meet the requirements of Annex VI. As low-sulfur fuel is expensive and often difficult to obtain, many shipowners have started to install emission scrubbing systems on their vessels. Some

have started to "slow steam," which burns less diesel fuel so that emission standards can be met, although market pressures associated with delivery schedules do not make this an attractive option. Other shipping companies have divided their fuel tanks into low-sulfur diesel and regular sulfur diesel systems. Low sulfur is burned in SECAS designated zones and regular sulfur diesel is used outside those zones. Still others have decided to use low-sulfur fuels for all maritime operations (the green option). Regardless of the approach being used, the days of unfettered air pollution from seagoing vessels are rapidly coming to an end.

*See also* AIR POLLUTION; CARBON DIOXIDE; CARBON MONOXIDE; CONTINENTAL SHELF; DDT; NO<sub>x</sub>; PARTICULATE; PESTICIDES; SULFUR DIOXIDE.

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### LEGISLATION ON MARINE DUMPING

In the United States, restrictions on ocean dumping were instituted in 1972, when Congress passed the Marine Protection, Research, and Sanctuaries Act. For the first time, a permit was required to dispose of materials in the ocean. General permits were issued for activities found to have a minimal environmental impact, such as burials at sea, the sinking of U.S. Navy target vessels, and the disposal of vessels in the ocean. More importantly, special permits were required by any person wishing to discard material into the ocean or to transport material from the United States for ocean dumping. Material that was used for biological warfare or had high levels of radioactivity could no longer be disposed of at sea.

In the late 1980s, legislators were galvanized into further action when syringes, vials of blood, and other medical waste washed up on beaches in New York, Connecticut, and New Jersey after heavy spring rains. The 1988 Ocean Dumping Ban Act and Public Vessel Medical Waste Anti-Dumping Act were passed and signed into law. These acts added sewage sludge, industrial waste, and medical waste to the list of materials that could no longer be discarded into the ocean. Exceptions are allowed to protect the health and safety of the crew or in the event of war or national emergency. These and other regulations have been effective in reducing the amount of ocean dumping. As a result, dumping of sewage sludge was reduced from 18 million tons (16.3 million metric



tons) in 1980 to a little more than 12 million tons (10.9 million metric tons) for all of the 1990s.

Internationally, the pressure to curtail ocean dumping started to build in the early 1970s. The United Nations General Assembly convened the 1968 Conference on the Human Environment and another in 1972 to focus on issues that laid the groundwork for today's environmental consciousness. Effectively describing the threat to the ocean that indiscriminant dumping posed, these beginnings led to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, a 1975 meeting in London that established guidelines on the ocean disposal of industrial wastes. In November 1993, signatory countries to the London Dumping Convention, as it came to be known, also agreed to ban the disposal from ships of radioactive waste. More than 80 countries signed these prohibitions, which were similar to those put into place by the United States. The United Nations International Maritime Organization was given responsibility for this agreement and a more formal protocol was adopted in 1996. Many poorer countries, however, continue to struggle with both enforcement of ocean dumping bans and the development of alternate disposal methods.

Waste materials discarded into the seas are called black list, gray list, or white list items. Black list wastes are chemicals such as organohalogens, mercury, cadmium, plastic, petroleum products, highly radioactive substances, and biological or chemical warfare agents. Gray list materials include arsenic, copper, lead, zinc, organosilicon-contaminated liquids, cyanide, fluoride, pesticides, acids and bases; certain metals, such as beryllium, chromium, nickel, nickel compounds, and vanadium; and scrap metal, low-level radioactive materials, and other compounds that affect the ecosystem. White list items are all other materials not included on the black or gray lists. These are materials that can be safely discarded, so long as it is not done in vulnerable areas, such as coral reefs.

### DREDGING AND SPOILS

Today, the majority of environmental concerns related to ocean dumping are focused primarily on the unrestricted, open-water disposal of dredge spoils. To keep ports and harbors accessible to boat traffic for recreation, commerce, and defense, several hundred million tons of silt and sediment that accumulate naturally in coastal channels and near docks and other harbor facilities must be periodically removed. Dredging is done to remove sediments that have been contaminated by industrial pollutants. In the United States, almost a half-billion

cubic yards (394 million m<sup>3</sup>) of sediment is dredged annually by federal, state, and local governments, as well as by private organizations such as cargo terminals, marinas, and yacht clubs.

The dredged material is removed from active shipping channels, ports, and harbors; some of it (about 10 percent, according to U.S. Environmental Protection Agency [EPA] estimates) is typically contaminated with heavy metals and organic chemicals such as hydrocarbons or pesticides that were released into the water from ships and harbor operations, as well as carried downstream by runoff from farms, roads, and discharges from industrial sites and wastewater treatment plants. Until the early 1990s, most of this dredged material was loaded onto ships or barges and dumped farther offshore at specially designated sites, away from seagoing traffic. There were concerns, however, about the ecological impacts of concentrating potentially contaminating sediment in one place and its possible relocation by ocean currents. In response, other disposal alternatives are now used to manage about 80 percent of dredged material nationwide.

These disposal alternatives include either confined disposal or beneficial reuse. Confined disposal is the placement of contaminated dredged material within an excavated offshore area or in a secure upland area where its potential effect on the environment can be minimized. In New Jersey, the 70-foot- (21.3-m-) deep Newark Bay Confined Disposal Facility is intended to isolate contaminated sediment dredged from shipping lanes in the harbor cost-effectively. Beneficial reuse entails collection and relocation of noncontaminated dredged material for reuse as either landfill cover, road base, mine reclamation, or other types of "upland fill" in construction, land restoration, or habitat creation projects such as beach replenishment and island creation.

Decontamination technologies also are being developed to treat contaminated dredge materials and allow them to be more widely reused. Although treatment costs are a factor, especially because some projects require the management of thousands of tons of material, as the costs of decontamination and placement decline, this approach is becoming a more viable option.

To excavate dredge material within the navigable waters of the United States, a permit must be obtained from the U.S. Army Corps of Engineers (USACE). Permit applications are evaluated against environmental criteria developed by the EPA to protect the marine environment and assess potential impacts of ocean dumping on human health, shipping and transportation needs, and marine resources such as fisheries and recreation. If approved, dredging and disposal

activities are monitored by the USACOE and EPA to ensure that permit conditions including excavation depths, amount of material removed, handling, and disposal are followed. Similar permits are required for dredging projects in most industrialized countries, and the United Nations is helping developing nations to establish their own dredging control programs.

See also CONTINENTAL SHELF; GREENPEACE; INORGANIC POLLUTANTS; MARINE LITTER; PESTICIDES; RADIOACTIVE WASTE.

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### COMMONLY USED DREDGING TECHNIQUES

Name	Description	Application
Clearing and snagging	Special boats equipped with cranes winches, and grappling hooks are used to clear debris, unused piers, and sunken objects from channels and shipping lanes.	Used to remove large items or break up debris that has become a hazard to navigation.
Grab dredge	One or more crane-operated buckets mounted on a barge or a fixed shore facility. Each bucket has a hinged jaw, which closes when sunk into the sediment. Material is lifted to the surface and placed in a hopper for transport to a disposal area.	Used when relatively low volumes of material are excavated.
Dipper dredge or boom and dipper assembly	Similar to a power shovel, mounted on a movable or fixed platform, a cable operated scope is used to dig out sediment or soil for placement in trucks or hoppers.	Used in areas where access to construction equipment is not readily available. Very rugged and capable of removing hard-packed material. Also used in land-based canal digging and cutting projects. This technique was used to excavate the Panama Canal.
Ladder bucket or hopper dredge	Usually mounted on a ship built with a long, narrow opening (called a well) in the hull. A string of buckets, mounted on a steel frame above the well, is lowered into the water and used to scoop up sediment. Each bucket empties its load into a chute connected to either a barge or a bottom-emptying hopper.	Used when large volumes of material must be removed quickly and inexpensively from active shipping lanes. Works best in deep waters but cannot dredge continuously, and excavation is less precise than with other techniques.
Suction or hydraulic dredge (cutterhead dredge and self-propelled hopper dredge)	Material is sucked through a flexible hose mounted on the intake end, with a water jetting device that mixes and breaks up bottom sediment. At the discharge end, sediment is emptied into a hopper, where it settles and excess water is decanted.	Used primarily for the almost-continuous removal of soft sand or sediment but can excavate smaller loose rocks and debris. Material dredged in this manner can be moved through pipelines for long distances and be used in land reclamation activities. May be difficult to operate in rough weather.
Dustpan and sidecaster dredge	Dustpan dredge is a type of hydraulic dredge designed specially for the Mississippi River. Water jets at the end of the suction head agitate the sand into a slurry, which is then pumped up into the dredge. The discharge is sent to a pipeline and emptied a short distance, typically around 800 feet (246 m), outside the navigable channel. A cutterhead dredge has an active rotating auger surrounding the suction line. The material can be pumped much farther through a pipeline, up to 3,000 feet (0.9 km).	Used to remove loosely compacted, coarse-grained material in shallow sites or in areas where sediment can be used adjacent to or near the channel.

Note: Hopper barges are designed with hinged doors, or flaps that open downward. Around the storage space (cargo hold) are watertight compartments that provide buoyancy for the barge. When the barge is above the disposal site, the bottom doors open and sediment is released. Winches then close the doors and the barge is ready to receive its next load.

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**offshore oil production** In 2000, offshore oil production was more than 25 million barrels (3,975 million L) per day and accounted for more than 30 percent of global petroleum supplies. Similarly, offshore wells provided some 30 trillion cubic feet (0.9 trillion m<sup>3</sup>) of natural gas in 2000, with another 6 trillion cubic feet (0.2 trillion m<sup>3</sup>) of production expected by 2020. There are large reserves of petroleum and natural gas on the outer continental shelf of the United States, especially off the coasts of California and Alaska and in the Gulf of Mexico. One study estimated that 30 percent of the undiscovered gas and oil reserves in the United States is within its coastal territorial waters.

### DEEP-SEA DRILLING

The exploitation of these reserves has a steep environmental price tag. The process begins with finding the oil or natural gas, which typically is done through prospect mapping using geophysical surveys and results from other wells. The objective is to find a geological structure, called a trap, where oil or gas has accumulated and can be extracted. Once the subsurface structure or trap has been identified, a series of exploratory wells are drilled to determine whether oil or gas is present in economic quantities. If so, a series of development wells are drilled to remove the petroleum. Three basic types of equipment are used to drill a typical offshore oil well. These include a drillship, with drilling equipment mounted on its deck that can be advanced through an opening in its hull. Anchors often are driven into the sea bottom to allow the drillship to maintain its position. More sophisticated systems, however, use a series of powerful computer-controlled thruster engines mounted on the ship to stay on station over the borehole. Drillships can operate in waters 2,000 feet (610 m) deep or more.

A jackup rig is a floating barge equipped with massive extendable legs that is towed to the well site. The legs are lowered onto the seafloor and raise or "jack up" the barge off the surface of the water so that it becomes a more stable drilling platform. These types of rigs can be used only in relatively shallow water (less than 500 feet, or 152 m, deep).

A semisubmersible is also mounted on a barge, but instead of extendable legs, the barge is equipped with large pontoons. Once on station, the pontoons are flooded and drag the hull of the barge down to just below the waterline. It is then anchored to the seafloor with cables. This type of setup can be used in waters between 500 feet (152 m) and 2,000 feet (610 m) deep.

Once the location for an offshore oil or natural gas well has been identified, a more permanent drilling platform is constructed. Usually installed on fixed legs, platforms are very large steel-shelled structures with a deck extending just above the water line. The deck rests on a complicated series of large-diameter pipes (the "jacket") welded together and extending to the seafloor. Once the well is drilled to the desired depth, the oil or gas is delivered into a subsea pipeline. Many of these pipelines are hundreds of miles long and connect platforms to a refinery or distribution center.

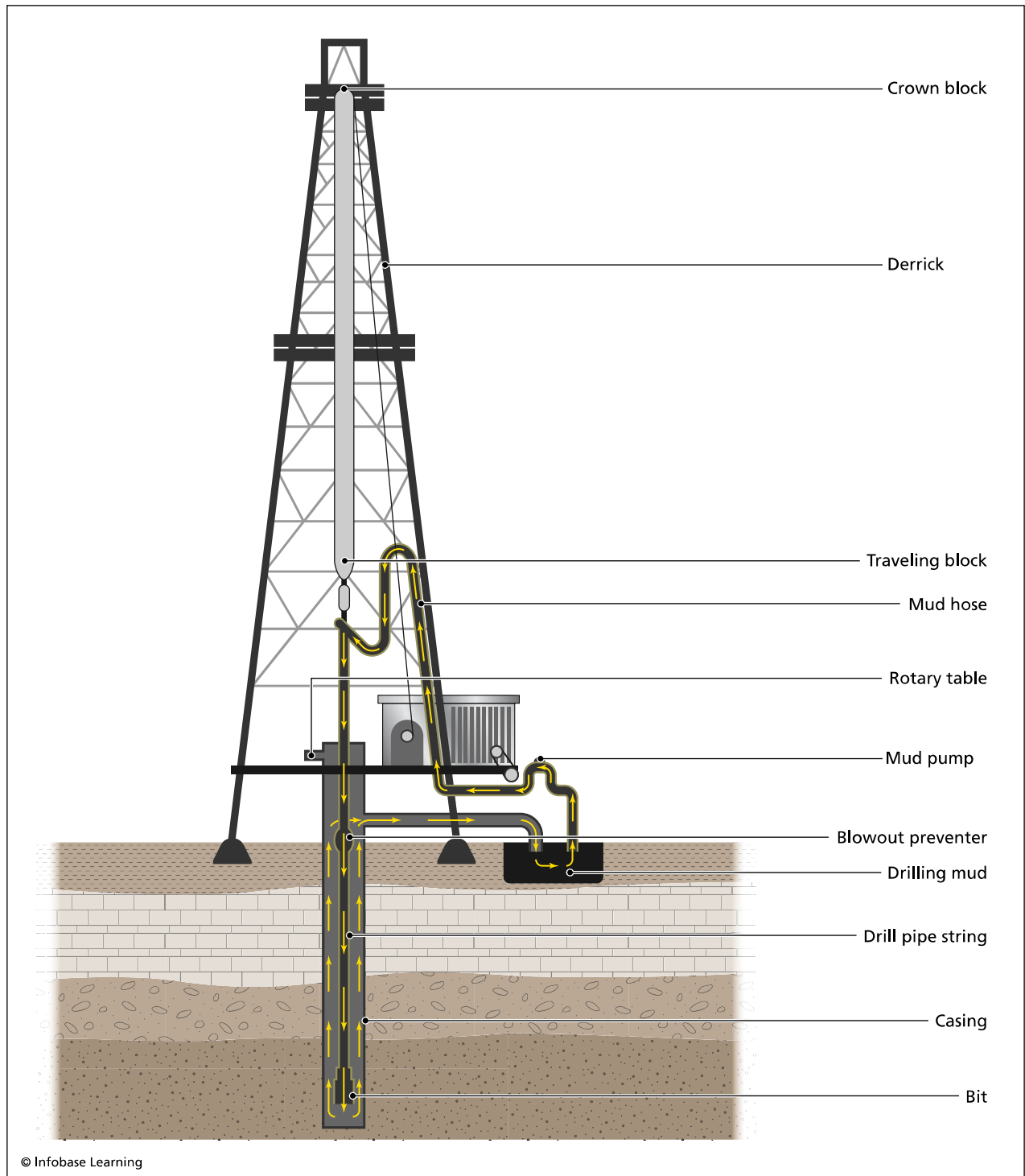
Each of these steps, exploratory drilling, and platform installation, followed by laying of pipeline, can negatively affect the marine environment. Environmental effects of well-conducted exploratory oil drilling are usually short-term and modest. Care must be exercised to avoid fish-spawning or other ecologically sensitive areas and to ensure that waste products from equipment operation are managed appropriately. In the construction of the more permanent structures, however, habitat for benthic organisms, many of which form a critical part in oceanic food webs, can be destroyed. Fish and other marine organism breeding or migratory patterns also can be disrupted. Pipelines can leak and discharge oil into the ocean, and waste from drilling and platform maintenance can result in localized pollution. Unquestionably, however, the chief environmental risk posed by offshore oil and gas production is a blowout.

### BLOWOUTS

The oil and gas present in the geologic reservoir, or trap, are under immense pressure because they are buried beneath thousands of feet of sediments below the ocean floor. Unless special precautions are taken during drilling, when the well penetrates the accumulation, oil and gas rush to the surface in

an uncontrolled release, called a blowout. Blowouts often result in intense fires because of the flammable nature of the oil and gas. The fires are extremely dangerous and very difficult to extinguish. Blowouts

from offshore wells often result in severe ecological damage because the oil is released directly into the ocean, in immediate contact with sea life and their fragile habitats.



**Simplified illustration of a modern petroleum-drilling rig. Basically, the crown block, derrick, and traveling block are involved in installing or removing components from the well. The rotary table provides the turning power to the drill pipe string and ultimately the bit at the base of the well. The drilling mud is pumped by the mud pump through the mud hose and into the well for lubrication and for removal of debris. The casing and blowout preventer keep the mud and petroleum in the well.**



There are two ways to prevent oil well blowouts: mud management and blowout preventers. As the drill bit is advanced into the rock and sediment, the materials crushed by the bit must be removed. This is done by using a mixture of clay and water called drilling fluid or mud. To be effective, the mud must be dense enough to carry the cuttings of rock to the surface, but not so dense as to interfere with the turning of the drill bit. Well drillers train for years in order to master this balancing act. Drilling mud also has another very important purpose. It can be used to keep the oil and gas out of the well until drilling is finished and the well is connected to oil or natural gas collection and distribution pipelines.

During drilling, mud pressures are monitored continuously to ensure that the drilling fluid is heavy enough to keep the oil or natural gas out of the well. The pressure within the well, however, can increase suddenly as unexpected changes in rock types are encountered. This rapid and often unpredictable pressure change, called a kick, can force mud and oil or natural gas up through the well pipe and onto the surface, resulting in a blowout. Carefully checking mud densities and levels, maintaining adequate circulation, and measuring bottom hole pressures, all help to prevent a blowout when a kick occurs.

The use of drilling mud can have significant environmental consequences. These muds are formulated by mixing together natural clays with special additives. Once circulated out of the borehole and on the platform, the mud is processed to remove the rock cuttings and then returned to the borehole. The cuttings, which can contain up to 15 percent of the mud, are discharged into the sea. The following are three basic types of muds used in offshore drilling applications.

#### **Oil-based muds (OBMs)**

These muds are used when drilling through host rock containing minerals, often present in shale, that absorb water. This loss of water results in a loss of borehole pressure that can lead to a blowout. Adding diesel fuel and/or mineral oil to the mud enables it to lubricate more efficiently, allows for better pressure control inside the well, and reduces the chance the drill pipe will become stuck. OBM also is the mud of choice when drilling boreholes that are not vertical. The U.S. Environmental Protection Agency (EPA), however, does not allow the discharge of OBMs or their cuttings from offshore platforms, making their use and management cost-prohibitive except in very limited circumstances. Oil-based muds and synthetic-based muds are

sometimes grouped together in a category called nonaqueous-based fluids, or NABFs.

#### **Water-based muds (WBM)**

Inexpensive and readily available, these types of drilling fluids are made up primarily of clay (bentonite) and either salt water or freshwater and include barite, a barium-rich heavy mineral used to add weight; caustic soda; lignite coal; or lignosulfonates. Water-soluble polymers are sometimes mixed in to stabilize the drilling fluid during use and to reduce corrosion and bacterial activity. WBMs have long been the mud of choice for the drilling companies because the used mud and cuttings can be discharged from platforms in many U.S. offshore waters (except Alaska), as long as they meet permit limits. They typically do not cause significant environmental problems for marine life or benthic ecosystems.

#### **Synthetic-based muds (SBMs)**

The use of synthetic-based muds, in which the base fluid is an organic chemical such as olefins, ethers, esters, or acetal, has been increasing in U.S. waters, as well as offshore operations of other major oil-producing countries. An olefin is an alkene hydrocarbon from ethene. Ether is derived from the distillation of ethyl alcohol with sulfuric acid. An ester is a class of organic compounds produced from an organic acid and an alcohol. Acetal is a class of compounds formed from the oxidation of alcohol. SBMs have several technical advantages over WBMs, particularly when drilling in very deep water or a nonvertical borehole. They generate fewer cuttings than WBMs and are easier to process and recycle. Also, SBMs are not as toxic as OBMs, tend to degrade more rapidly, and are less likely to bioaccumulate. Given these properties, SBM cuttings can be discharged from offshore platforms, although the spent fluids must be contained and sent ashore for treatment and disposal.

The environmental and scientific communities are not in agreement about the way drilling fluids should be managed. Offshore platforms can discharge millions of gallons of mud every day. Once in the ocean, the cuttings and muds can accumulate in significant volumes. Even a small well by today's standards can generate up to 95,000 cubic feet (2,767 m<sup>3</sup>) of cuttings. Several studies have shown that mud and cuttings can inhibit sea grass growth and interfere with coral development. The oil industry has responded by looking at techniques such as mud reinjection and drilling of smaller-diameter boreholes. As regulatory pressure on the management of drilling fluids and cuttings increases, it is only a matter of time until most platforms reach zero-discharge status.

## BLOWOUT PREVENTERS

The second line of defense in blowout prevention is the use of special valves installed on the wellhead. This device, called a blowout preventer, or BOP, forms a seal at the top of the well and is automatically activated to stop the uncontrollable flow, or blowout, of formation fluids (mud, oil, or natural gas). BOPs are fixed atop the wellhead in an array designated as the BOP stack. This array or stack typically contains either a ram, annular, or rotating BOP along with associated valves and piping. These types of BOPs can also be used in combination.

Blowout preventers are mounted directly to the wellhead in combinations, called the BOP stack. This stack may contain one or all three types of BOPs. However, the primary well-drilling control is the hydrostatic pressure exerted by the drilling mud pumped into the borehole. The BOP is the second line of defense and provides a safety margin in the event of a sudden loss of drilling fluid pressure.

## PRODUCED WATER

After an offshore oil or natural gas well goes into production, it generates produced water. Hydrocarbon reservoirs contain water that was deposited along with the organic material that was eventually compressed and distilled over time to make oil. This water is denser than oil and tends to accumulate at the bottom of host rock formation. When oil is pumped from the well, water is drawn up with it. This water must be separated from the hydrocarbon before the oil or natural gas is sent to market. Sometimes, to increase production efficiency, additional water is injected into the reservoir. Both types of

water are called produced water. Its salt content is high, almost 10 percent, and produced water can also contain elevated concentrations of dissolved solids, volatile and extractable organic compounds, ammonia, hydrogen sulfide, and heavy metals, such as arsenic and copper.

Once out of the well and separated from the oil, produced water is managed in several ways. In many cases, it is reinjected into the well. On some platforms, special wells are drilled and produced water is injected into other geologic formations. When there is no other practical alternative, produced water is discharged into the sea. No matter how efficient the treatment process, produced water always contains some amount of oil, and its discharge is carefully regulated. In U.S. waters, the Clean Water Act requires a permit under the National Pollutant Discharge Elimination System (NPDES). These permits regulate the quantity and quality of produced water that can be released from the platform.

Some scientists and many environmentalists maintain that current regulations related to the discharge of produced water are not sufficiently protective. They are concerned that the sheer volume of produced water generated during the operational life of a platform will overwhelm the dilution capability of the receiving body of water. For example, over the next 35 years, more than 2 billion gallons (7.6 billion L) of produced water will be discharged into the Gulf of Mexico. Some studies have detected oil and produced water residues in ocean sediments far downcurrent of platforms, especially those that have been operating for a decade or more.

Several European countries have moved to eliminate the discharge of produced water. Two major

## BLOWOUT PREVENTERS

Type	Description
Ram	Highly reliable and the principal pressure control tool used in oil well drilling. Sealing elements (rams) are on opposite sides of the blowout preventer. Operated by hydraulic cylinders, when open, they provide an unobstructed passage through the borehole. When closed, they seal off the open hole. Some types of rams, when activated in an emergency, will even shear off all the tools at the surface and seal the borehole without the need to remove the drill rods or bit.
Annular	Versatile tool able to seal off the borehole regardless of the tools or drilling equipment present in it. When activated by a piston, annular BOPs form a seal in the open (annular) space between the drill pipe and the borehole. It acts as a tight-fitting collar around the drilling tools present in the well, keeping them in place and preventing a sudden release of pressure.
Rotating	A low-pressure device, used in special situations when the hydrostatic pressure of the drilling fluid is less than the formation pressure, which allows drilling to proceed faster. It is attached to the top of the drill rod by a quick-release bonnet and rotates with it. When activated, the sealing element closes around the drill rod and seals off the borehole.

Norwegian oil fields usually do not discharge produced water, either reinjecting it or storing and offloading it into barges for treatment at land-based facilities.

*See also* ARSENIC; BARIUM; CONTINENTAL SHELF; EKOFISK OIL FIELD; IXTOC I OIL SPILL; OIL SPILLS; SANTA BARBARA OIL SPILL.

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**Ogallala Aquifer** One of the major aquifers in the United States, the High Plains Aquifer, is predominantly composed of the Ogallala Aquifer, named for the geological formation that contains the aquifer. This aquifer produces 30 percent of all water for irrigation in the United States. It underlies parts of eight states (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming), covering a total area of 174,000 square miles (450,000 km<sup>2</sup>). This area contains 20 percent of the nation's cropland, making it one of the most important agricultural areas. Use of water withdrawn from the entire High Plains Aquifer is 94 percent for irrigation, with the remaining 6 percent supplying 82 percent of the drinking water needs in the area. Parts of the area contain water that is so saturated with natural contaminants that it is of questionable safety. The major problem, however, is that the huge removal of water from the Ogallala Aquifer is quickly dropping the water levels, creating a serious situation that is currently being addressed by the U.S. Congress.

#### **GEOLOGIC HISTORY**

The Ogallala Formation was named by N. H. Darton in 1898 for the town of Ogallala, Nebraska, where it is best exposed. The major depositional

history of the unit was from Late Miocene–Early Pliocene to Late Pliocene, about 6 million to 2 million years ago. After the Rocky Mountains were built by the Laramide Orogeny, the area was uplifted, draining the great Cretaceous seas that covered the central United States. The older Permian, Triassic, Jurassic, and Cretaceous rocks were exposed at the surface and subject to extensive weathering and erosion as large rivers began draining the eastern slopes of the Rocky Mountains. These rivers flowed eastward, carving deep valleys and channels into the preexisting rocks and sediment. Strong winds also carried significant amounts of sediment off the mountains and into the plains below. The earliest deposits are gravels and coarse sands in the base of the river valleys, but coalescing aprons of sediment covered the entire eastern base of the mountains, and braided streams formed a large depositional plain across the western edge of the Great Plains. Sediments covered the entire area and reached a maximal thickness of 900 feet (274 m). In the northern High Plains, the Ogallala Formation is divided into three members (subdivisions), named the Valentine, Ash Hollow, and Kimball, for the fossil vertebrates and plants that they contain. These subdivisions are unrecognizable to the south.

The basal gravels that fill the old river channels range from boulder to pebble size and are mostly composed of quartz, quartzite, chert, and caliche with lesser amounts of limestone. The overlying sands are tan to reddish and are generally finer (smaller) to the east. The sand is locally interlayered with thin shale layers, but they are minor. There are also small zones where the sand has been cemented with calcite and gypsum less frequently, and there are caliche horizons as well. In Texas, caliche is so well developed that it forms an impermeable caprock both on the Ogallala and on succeeding depositional units. In Texas and New Mexico, the gravels that fill the old valleys are similar to the rest of the Ogallala Formation, but much of the overlying sand is wind-blown, indicating arid, aeolian conditions. This is supported by the presence of evaporates and caliche. Fine windblown material called loess is far less permeable than fluvial sands.

#### **WATER CAPACITY, PRODUCTION, AND QUALITY**

The Ogallala Aquifer contains an immense amount of groundwater. The water-saturated thickness of the aquifer ranges from a few feet to an estimated 525 feet (160 m). In general, the thicker water-bearing section is in the northern plains, with the saturated zone in the southern plains ranging from 50



**The Ogallala Aquifer stretches for 800 miles (1,300 km) through South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, Texas, and New Mexico.**

feet (15 m) to 200 feet (61 m) at maximum. Depth below the surface to this saturated zone ranges from 400 feet (123 m) in parts of the northern plains to approximately 100–200 feet (30–61 m) through most of the southern plains.

The quality of the water is variable. Dissolved solids range from about 0.03 ounce per gallon (250 mg/L) of water to more than 0.13 ounce per gallon (1,000 mg/L) locally, with the vast majority of measurements below 0.07 ounce per gallon (500 mg/L). Crops can tolerate water with dissolved solids below 0.07 ounce per gallon (500 mg/L) but may experience problems with higher concentrations. The principal dissolved solid north of the Arkansas River is sulfate from gypsum weathered out of Upper Cretaceous rock directly beneath the aquifer. This area contains the highest levels of dissolved solids. South of the river, the main dissolved solids are calcium-magnesium bicarbonate. Where there is hydraulic interaction with the underlying units, there is local input of

mineralized waters that degrade the water quality of the aquifer.

Pumping of water from the Ogallala Aquifer began in the 1800s using windmill powered pumps, but large-scale withdrawal did not begin until after the great drought of the 1930s. By 1949, up to 10 percent of the land, or 2.1 million acres (850,000 ha), overlying the aquifer was irrigated. By 1980, the irrigated area was up to 13.7 million acres (5.54 million ha), and, by 1990, it was 13.9 million acres (5.63 million ha). Annual withdrawal of water from the aquifer has exceeded recharge since the 1960s. The height of the water table in the Ogallala Aquifer has decreased up to 175 feet (54 m) in some areas, with an average of 100 feet (30.8 m). The rate of decline ranges from 1.4 feet (0.4 m) per year to 1.7 feet (0.5 m) per year at most, but it is actually rising in other areas. The rapid drop in water level has changed the Arkansas River from effluent to influent. Whereas the Ogallala and overlying aquifers previously fed the river from springs, between 1995 and 2000, the average aquifer recharge from the river was 100,000 acre-feet ( $1.2 \times 10^8 \text{ m}^3$ ) in Kansas. During dry years, the Arkansas River can dry up. The Canadian River and South Platte River are still effluent, but they are receiving less groundwater recharge every year. At the current rate of decline of the water table in the aquifer, they will reverse to influent rivers as well. Even land under canals and land irrigated with diverted river water is now recharging the aquifer in many areas.

The largest loss of water in the area above the Ogallala Aquifer occurs through evaporation. This process tends to concentrate ions and contaminants in remaining water. With all of the irrigation comes excessive use of fertilizers and pesticides to improve crop output. Instead of a few aquifer recharge zones in areas of coarse sand at the base of the mountains, aquifer recharge is much more widespread. With the degradation of surface water quality and increase in infiltration, the quality of the water in the Ogallala Aquifer is expected to decrease even further in coming years. This excessive loss of water and threat to the health of the Ogallala Aquifer is such that the U.S. Congress is considering bills to regulate water use in this area.

*See also* AQUIFER; INFLUENT/EFFLUENT STREAMS; PESTICIDES; STREAMS; WELLS.

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**oil spills** As our energy needs increase, humans use ever-increasing amounts of oil. To produce such vast quantities of oil at such a fast rate requires complex technology with ever-increasing handling capacities. High volume and rate technology can be an economic boon to producing areas, but even small mishaps can result in disastrous oil spills that devastate the environment. The oceans typically suffer the most environmental degradation from oil spills. By far the two most spill-prone operations in the ocean are drilling and producing offshore oil wells and fields and transporting the oil in tankers and super-tankers. There are many other sources of oil entering

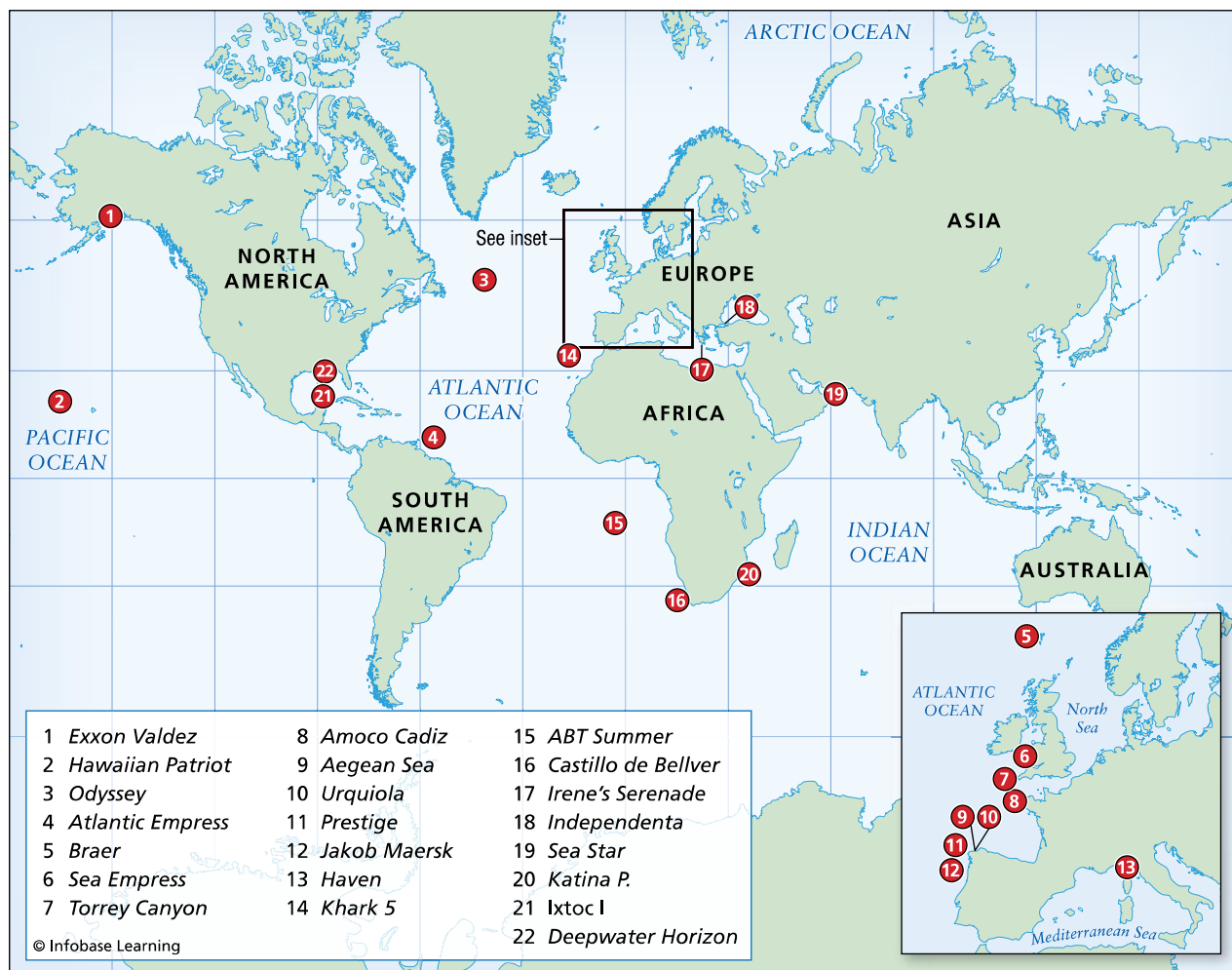
the ocean ranging from boats to surface runoff, but the volume from these is far smaller.

Recent studies indicate the average discharge of oil into the oceans and navigable waterways is 42.7 million gallons (161.6 million L). This average does not include the several years of megaspills of 125–335 million gallons (473–1,268 million L). The megaspill years include, in decreasing order, 1991, 2010, 1979, 1983, 1978, and 1980. The frequency of these megaspill years has decreased recently as a result of greatly improved safety procedures and devices, although an event may occur at any time but especially during natural disasters. Typically, a single incident defines a megaspill year.

Oil spills from grounded and damaged tankers or from accidents during transfer of oil to a storage facility commonly occur in coastal areas. They cause severe environmental damage and loss of marine life on beaches and especially in estuaries, which are ecologically sensitive. They also have an economic impact in direct cleanup costs, beach closings and other recreation losses, damage to sport fish and bird populations, and diminished



Oil well being installed near Fort Lupton, Colorado, 2006 (Rick Wilking/Reuters/Landov)



**Map of the world showing the locations of select oil spills from both tankers and blowout of oil wells (Many of the spills are described in this book.)**

property values. Oil spills from platforms may also be close to shore or in deeper water. Coastal spills from platforms present essentially the same problems as those from tankers. Deep-water spills do not directly affect shore communities or coastal marine and bird life. It is difficult to assess the effect of oil spills on deepwater marine life because it cannot be observed directly.

Americans became acutely aware of the potential damage from oil platform spills when a Union Oil well suffered a gas blowout on January 29, 1969, in the Santa Barbara Channel, California. The well was quickly capped but built-up pressure forced oil from the seabed for 11 days. In total, some 200,000 gallons (760,000 L) was spilled, covering 800 square miles (2,048 km<sup>2</sup>) and killing 3,600 shore birds and innumerable fish, dolphins, and seals. It was not a large spill, but its visual impact on American television is credited to have fueled the environmental movement into a position of prominence.

The June 3, 1979, blowout of the Ixtoc I well in the Campeche area of offshore Mexico was the largest spill of all time of any kind, with an estimated loss of 140 million gallons (532 million L). The April 20, 2010, blowout of the *Deepwater Horizon* in the Gulf of Mexico was even larger, with 204 million gallons (775 million L) spilled. Both of these spills are dwarfed by the mammoth spill that began in January 1991 in the Persian Gulf during Operation Desert Storm. Considering that so much of the world's oil is from the Persian Gulf and is shipped out by tanker, regular oil spills are a way of life. It is estimated that, on average, 230,000 gallons (950,000 L) of oil is spilled into the Persian Gulf through routine operations per day. As a result, it has been called one of the world's most polluted water bodies. The eight-year Iran-Iraq War involved the regular bombing of oil production facilities and greatly increased the annual average of spills during that period. One damaged

oil rig poured out 54,350 gallons (205,737 L) of oil per day for three months.

Despite the tremendous amount of oil spilled on a regular basis in the Persian Gulf, the catastrophic event of the Gulf War was required to make the problem so prominent. It is estimated that 252.8 million gallons (957 million L) was spilled through a combination of sabotage of the fields by the Iraqis, bombing, and a major battle site at a refinery. The oil slick covered some 350 miles (570 km) of the Saudi Arabian coastline and would have been much larger were the waves and currents in the Persian Gulf not so small. Nonetheless, oil spill experts from United States, Great Britain, Netherlands, Germany, Australia, and Japan rushed to the area and managed to protect the input pipes at desalination plants and refineries, though marine life was strongly affected. It is estimated that half of the oil evaporated, 94.8 million gallons (359 million L) was recovered, and the rest sank to the bottom of the Persian Gulf.

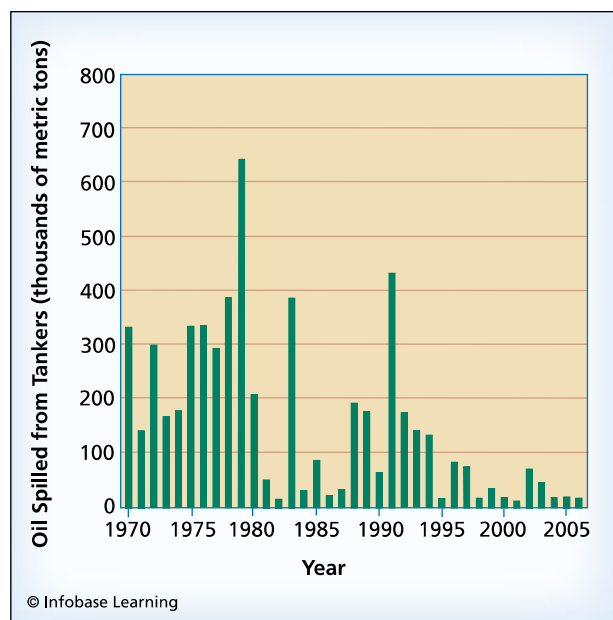
Tanker and transfer accidents can also produce devastating effects. As tankers were built ever larger to carry ever-increasing amounts of oil, the impacts of accidents have become increasingly devastating. The first ultralarge tankers, called supertankers, were developed in the late 1960s, and the first accident with a supertanker was the *Torrey Canyon* spill of March 18, 1967. The tanker hit some rocks off the southern coast of the United Kingdom and inundated the coast with oil. The effect on sea life and coastal communities was devastating and exacerbated by ill-conceived cleanup strategies by the military.

Just 11 years later, on March 16, 1978, the *Amoco Cadiz* ran aground on the English Channel side of the United Kingdom and broke up on the rocks, spilling some 66.4 million gallons (251 million L) of oil into the channel. Gale force winds and a particularly high tide spread the spill over more than 180 miles (300 km) of French coastline. In all, some 3,000 birds died, and oyster farms and fishing suffered greatly.

The United States has not escaped the devastation of a tanker accident and spill. The March 1989 grounding of the *Exxon Valdez* is the most famous of these, though the volume of the spill is much smaller than that of many others. The tanker hit a reef in Prince William Sound, tearing a large gash in the hull and spilling 35,000 tons (10.8 million gallons [40.8 million L] or 31,818 metric tons) of oil. The effect of the spill was greatly exacerbated by the remoteness of the area, strong tidal currents, rugged coastline, and severe weather. The spill spread quickly to cover more than 900 square miles (2,300 km<sup>2</sup>) and caused great damage to the fragile arctic ecosystem. By 1992, 13 percent of the spill had settled into the sediments, 2 percent was on beaches, 50 percent degraded naturally into the water, 20 percent evaporated, and 14 percent was recovered and removed.

Although the technology to produce, transport, and use large quantities of oil has been developed, the capacity to clean up spills or even to understand the best course of action lags woefully far behind. On average, only 8–15 percent of spilled oil is recovered, and that includes the mixed-in seawater. The methods for containment and removal are purely mechanical and include oil booms and oil skimmers, respectively. The booms surround the spill and prevent it from spreading. The most common skimmer is a catamaran with a moving belt. The oil adheres to the belt and is lifted into storage tanks. The methods are somewhat effective in protected areas, if the weather is good, but ineffective in all other conditions.

Onshore cleanup methods are typically more damaging to the environment than the spill itself. The initial spill is very damaging to marine life that cannot escape and to birds, depending upon the season. Oil flattens feathers and reduces the birds' resistance to cold. Oil can clog the fishes' gills and slowly suffocate them and can similarly clog filter feeders. Once it begins to thin, however, it is less dangerous, as the toxicity of weathered crude oil is relatively low. It is at this point that the cleanup teams typically arrive. They use harsh dispersants and detergents that commonly kill more wildlife



**Graph of total tonnage of oil spilled from tanker accidents versus years (time) from 1970 to 2006**



than the oil. Hot water is sprayed onto the beaches with high-pressure hoses (100 psi or 6.8 bars) that stream barnacles, snails, and other animals that cling to the rocks. They cause excessive erosion of the beach and drive the oil deeply into the sediments where it is less prone to evaporation. The other common method is to spread hay on the beach to soak up the oil and then rake it off. All of these procedures involve numerous vehicles, heavy equipment, hoses, camp sites, and scores of people trampling through the already-damaged area.

Recent studies indicate that the best method to address oil spills is to prevent them from reaching the shore in the first place. Spraying them with low-toxicity dispersants and developing more effective physical barriers are two recommended strategies. The addition of nutrients to the beaches to increase the microbial populations that hasten the breakdown of oil and the addition of oil-degrading strains of bacteria to the area are also under evaluation. It is fortunate that we transport oil in its crude form because refined forms, such as gasoline and diesel, are far more toxic.

*See also* AMOCO CADIZ OIL SPILL; BURMAH AGATE OIL SPILL; EKOFISK OIL FIELD; EXXON VALDEZ OIL SPILL; GULF WAR OIL SPILLS; IXTOC I OIL SPILL; SANTA BARBARA OIL SPILL; TASMAN SPIRIT OIL SPILL; TORREY CANYON OIL SPILL.

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**Omaha lead site Omaha, Nebraska (1987–present)** *Air and Soil Pollution* The 23-acre (9.3-ha) ASARCO lead processing facility in Omaha, Nebraska, left a legacy of soil contamination that local residents and environmental regulatory agencies are still struggling to overcome. Formerly the American Smelting and Refining Company, ASARCO is a copper and minerals production company headquartered in Arizona and owned by

Grupo Mexico, the third largest copper producer in the world. Between 1871 and 1997, at 500 Douglas Street along the west bank of the Missouri River on the eastern edge of downtown Omaha, ASARCO and its predecessor companies processed lead ore that contained economically recoverable concentrations of gold, silver, antimony, and bismuth by using a pyrometallurgical process.

#### OPERATIONS OF THE PLANT

Concentrated lead ore was received at the ASARCO plant in Omaha and then calcined by roasting and mixed with charcoal and a flux of limestone. This mixture then was melted in a blast furnace to separate the lead from other impurities in the ore. Compounds of the impurities floated to the top of the molten metal as slag and were physically separated from the purified lead concentrate, called bullion. Depending upon the level of purity required, the process was repeated a second or even third time to ensure removal of all but trace levels of impurities. The “impurities” in the lead were actually valuable commercial and industrial minerals such as gold, silver, and bismuth. The recovered slag, which was collected and sent for refining, often had a greater value than the lead bullion. At the Omaha plant, final products included finished lead, as well as specialty metal by-products such as antimony-rich lead, bismuth, dore (a mixture of gold and silver in cast bars), and antimony oxide. Refined lead was shaped into 100-pound (45.4-kg) cylinders or one-ton (0.91-metric-ton) blocks that were then shipped to ASARCO customers.

#### POLLUTION OF THE SITE

Each time the ore was heated, waste materials were generated in the form of lead- and sulfur-enriched dust and fumes. In today’s modern mineral processing plants, air pollution control devices such as baghouses and scrubbers collect the vast majority of these dusts and fumes, and they are either reused in the process to make sulfuric acid and other economic compounds or disposed of in accordance with local waste management regulations or plant permit requirements.

During the majority of the facility’s operational life, the air pollution control devices were minimal, and, as a result, dusts enriched with lead and other metals were discharged into the atmosphere through smokestacks and process vents. These dusts were carried by the prevailing winds and settled onto the ground in residential neighborhoods and commercial areas throughout Omaha.



In 1987–1997, the ASARCO Omaha facility released 400 tons (362.9 metric tons) of arsenic, lead, chlorine, and numerous other types of toxic materials into the atmosphere. Similar releases to the water (40 tons, or 36.3 metric tons) and soil (17 tons, or 15.4 metric tons) also took place during this period. In 1992, in large part because of releases, the air quality surrounding the plant was found to be in nonattainment for lead in terms of the Clean Air Act. This allowed the U.S. Environmental Protection Agency (EPA) to require that stringent and expensive air pollution control measures be implemented at the ASARCO facility. In 1995, rather than installing the almost \$40 million worth of air pollution control equipment needed at the plant, ASARCO announced that the Omaha facility would be closed. Final shut-down including demolition was completed in 1999, and plant grounds have been decontaminated and the site redeveloped by the city of Omaha for commercial and recreational uses.

A second lead smelter operated in Omaha from the early 1950s until 1983. Located only about 500 yards (457.2 m) west of the ASARCO plant, the Gould Electronics facility also smelted and recycled lead. This facility was a major contributor to atmospheric lead within the city. It, too, was torn down and the area reclaimed as a county park. Several other businesses within the city also used lead in manufacturing processes, but none was close to matching the quantities emitted by the ASARCO and Gould facilities. Some of the lead reported in soil in Omaha is probably related to lead-based paint and automobile exhaust from the former (pre-1986) use of leaded gasoline.

A year-long study conducted by the Douglas County Health Department screened blood lead levels in 2,800 children and found that almost 600 had lead levels of 10 micrograms per deciliter (mcg/dL) or higher. Research data indicate that concentration of lead in blood in excess of 10 mcg/dL in young children can impair intellectual development and cause reading and learning disabilities, impaired hearing, reduced attention span, hyperactivity, and antisocial behavior. As the extent of lead in soil, especially in residential areas, became known, local city government asked the EPA for assistance in identifying and remediating the problem.

### REMEDIATION OF THE SITE

Working under authority granted by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the EPA and its contractors added the properties to the National Priorities List as a Superfund site on April 30, 2004. They

defined the Omaha Lead Site through historical records, soil sampling at 22,000 residential properties, and public health data that include contaminated surface soils at residential properties, child care facilities, schools, and other residential-type areas within the city of Omaha. These areas, some as far as 2.5 miles (4 km) from the ASARCO plant, were impacted by air emissions from lead smelting operations. The Omaha Lead Site encompasses an area of approximately 8,800 acres (3,561 ha) and includes approximately 65,600 residents living within the identified contaminant zone. There are also 20 Omaha public schools with an enrollment of 11,700 students surrounded by lead-contaminated soil, and 240 child care facilities within a three-mile (4.8-km) radius of the center of the site along with parks, golf courses, wetlands, and other public recreational facilities.

Using blood lead levels to prioritize its response actions, the EPA first removed contaminated soil and replaced it with clean fill and grass sod at those schools, child care facilities, and private residences where blood lead concentrations in children were equal to or greater than 10 mcg/dL and where soil samples contained lead concentrations greater than 400 mg/kg. Removal actions were completed at 300 properties, not including the schools and child care facilities, which were addressed first, and action at 5,200 more is planned. Building interiors are also being sampled for lead dust; if they are above recommended levels, they are being cleaned. Lead in soil at nonresidential areas will be chemically stabilized and covered to reduce the possibility of human exposure. Costs for these cleanup activities are estimated at about \$80 million. By mid-2004 the EPA had spent almost \$13 million of public money to perform investigation and remedial activities.

ASARCO is implicated in more than 20 Superfund sites and has estimated environmental liabilities of more than \$500 million. In August 2005, ASARCO filed for bankruptcy, citing as one of the reasons the more than 100 environmentally related lawsuits and enforcement actions for which the company was being held responsible. As part of bankruptcy proceedings, ASARCO established a \$100-million trust fund with USEPA approval to be used solely for environmental cleanup. Some \$3 million from that trust fund was allocated to the Omaha Lead Site. It is interesting to note that just before declaring bankruptcy, Grupo Mexico, ASARCO's parent company, transferred a large portion of ASARCO's assets to a separate offshore holding company.

*See also* AIR POLLUTION; ARSENIC; LEAD; SOIL POLLUTION; SUPERFUND SITES.

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**opacity** One effect of particulate emissions is an increase in atmospheric opacity. As sunlight is blocked by a medium such as smoke or the tinted windows of a car, its opacity increases. Opacity is measured as a percentage; 0 percent opacity indicates that the medium through which light is passing has no effect on its transmission in the visible light spectrum. In contrast, an opacity of 100 percent indicates that no light is able to pass through the medium. Opacity, the amount of light blocked by a medium such as smoke, provides an indication of the concentration of particulate being discharged from a vent or smokestack. The higher the particulate concentration, the more light that will be blocked, and the higher the opacity will be.

Today, particulate emissions are measured by sophisticated devices called transmissometers. These instruments measure the amount of a known quantity of light that is able to pass through smoke. Transmissometers consist of a light source attached to one side of a smokestack or exhaust vent and a selenium photocell attached to the opposite side. The photocell is covered with an optical filter that measures the quantity of light it receives and matches it to the spectral response of the human eye. A zero reading from a transmissometer means 0 percent opacity or 100 percent transmission. It is the output recorded when the light is on and no smoke is present.

In the early 1900s, local and state health departments struggled with a way to measure particulate air emissions and to enforce nuisance laws related to the release of soot and ash. It was difficult to make a case because of the subjective nature of the observations. The definitions of heavy smoke, dense smoke, and so on, were too variable for many courts to feel very confident that they were treating the accused

in a fair and even-handed manner. This changed around 1910, when the Ringelmann chart began to be widely accepted as a way to measure opacity.

Maximilien Ringelmann was a French engineer, who, in the late 1800s, noticed that the amount of black smoke produced by a boiler was related to its combustion efficiency, or air-to-fuel ratio. Ringelmann thought that if the darkness (opacity) of the smoke could be reliably measured, it could be used to help adjust the combustion efficiency of the boiler. He designed a series of black grids on a white background that he placed 50 feet (15.2 m) away from the smokestack of the boiler. Ringelmann then compared the color of the smoke with the color on the grid and was able to adjust the air/fuel ratio in the boiler reliably to reduce the opacity of the smoke. In the early 1900s, the U.S. Bureau of Mines approved the Ringelmann chart for measuring smoke emission at coal mines. One Ringelmann meant the smoke had an opacity of 20 percent, or was blocking 20 percent of visible light. Two Ringelmanns meant that 40 percent of the light was being blocked for an opacity of 40 percent. With this semiquantitative, less subjective method now available, by 1920, municipalities throughout the United States had adopted the Ringelmann chart as an inspection and enforcement tool to control nuisance smoke.

Even though transmissometers are in wide use at most industrial and power generating facilities, human observers still play an important role in the monitoring of particulate emissions and the enforcement of air quality regulations. The Ringelmann scale has been replaced by a set of standardized specifications and procedures described in the U.S. Code of Federal Regulations. Individuals can be certified as visual emission observers by passing a rigorous training program at a qualified "smoke school." Those seeking certification must be able to estimate, within a certain percentage of accuracy, the opacities of 50 different types of black and white smoke. Visual emission certification is valid for only six months at a time, and smoke school training must be repeated twice a year to maintain certification. Once certified, visual emission observers are able to estimate the percentage of opacity of smoke being emitted from a stack or exhaust vent. This determination is legally enforceable and can serve as the basis for fines and other regulatory enforcement actions. Opacity observations are used regularly by the U.S. Environmental Protection Agency (EPA) and many state environmental programs as a quick and easy way to evaluate the effectiveness of a facility's air emission control program and to take enforcement action

when visual observations indicate acceptable levels are being exceeded.

See also AIR POLLUTION; INDOOR AIR POLLUTION; PARTICULATE.

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**organic pollutants** Pollutants can be generally categorized as organic or inorganic. Organic pollutants are overwhelmingly produced through biologic activity, although some can also be produced as a result of volcanic eruptions. They are compounds of hydrogen and carbon (hydrocarbons) in various bonding configurations and, in many cases, bonded to other elements as well. The most dangerous of the organic pollutants are derivatives of petroleum. Some of these derivatives are directly from distillation of petroleum and generally used as fuel or solvents. The remaining organic pollutants are dominated by chemically altered petroleum derivatives.

There are several overlapping classification schemes for organic pollutants, primarily based on their physical and chemical properties. The primary division for organic pollutants is whether or not they are prone to evaporation. Compounds that evaporate easily are volatile and generally fall into the category of volatile organic compounds (VOCs). The volatility of a compound is determined by its vapor pressure, which is the pressure exerted by the vapor in equilibrium with its condensed liquid in a sealed container. If a compound has a high vapor pressure, it evaporates more quickly than a compound with a low vapor pressure. VOCs have vapor pressures such that they readily evaporate under pressures and

temperatures of the Earth's surface and accumulate in the atmosphere.

As a subcategory of direct volatility, compounds that are dissolved in water may also be released into the air. The tendency of a dissolved compound to partition from the water to air is quantitatively known as Henry's constant (H). Just like direct volatility, it is a function of the vapor pressure of the compound but also its solubility in water. High H favors evaporation, and low H favors the compound remaining in the water.

Organic compounds dissolved in water can also partition between water and sediment at the base of streams and lakes. If a compound has a tendency toward being hydrophobic (dislikes water), it will be removed from the water and become fixed or sorbed onto the sediments, depending on the physical and chemical conditions. The measure of this tendency is the distribution or partition coefficient (Kd), which is greater for compounds that remain dissolved. As conditions change, the compound may desorb and be released back into the water. This fixing and releasing of compounds in soils and sediments slows the movement of the pollutant. The ratio of the velocity of the water to the velocity of the pollutant is called the retardation factor.

Another physical property that is used to classify organic pollutants is density. Compounds that do not readily dissolve in water are termed *nonaqueous phase liquids* (NAPLs) in the environmental industry. If a NAPL has a density less than that of water (1.0 g/ml), it will float on top of groundwater and surface water in the natural environment. Such compounds are light nonaqueous phase liquids (LNAPLs). If a NAPL has a density greater than that of water, it will sink through groundwater and surface water. Such compounds are dense nonaqueous phase liquids (DNAPLs).

#### PETROLEUM

The main source of organic pollutants is petroleum, whether directly from the crude oil source or from the synthetic organic compounds into which it is manufactured. The ultimate source of crude oil is plankton and biologic by-products in the oceans. When plankton die, they settle with the other organic material and clay to areas of low wave and tide energy, such as lagoons, bays, and the deep oceanic plains. With time, this organic material is buried under thick sequences of sediment that heat and pressurize it. The changing physical and chemical conditions convert the organic material first into kerogens and later into oil and natural gas through a series of chemical reactions. These liquid and gas-

eous hydrocarbons migrate into geologic features called traps, where they can accumulate for an indefinite period of time, typically millions of years.

Crude oil is almost exclusively obtained from the petroleum traps through drilled oil wells. The only other way that it reaches the surface is through seeps or tar pits, but the amount is very minor and it flows so slowly that, in most cases, it can be broken down and removed by natural processes. Crude oil is composed of 83–87 percent carbon, 10–14 percent hydrogen, up to 6 percent sulfur, up to 2 percent nitrogen, up to 1.5 percent oxygen, and less than 1,000 parts per million of assorted metals. The compounds of crude oil are a mixture of numerous hydrocarbon types in various proportions. These hydrocarbons are classified into several chemical forms, including paraffins or alkanes, naphthenes or cycloalkenes, aromatics, and asphaltics in order of increasing density and thickness.

Crude oil is commonly classified by its density or gravity using the American Petroleum Institute (API) scale. API gravity is measured in degrees using the formula:

$$(141.5/\text{Specific Gravity of the oil}) - 131.5 = \text{API Gravity}$$

Crude oil that is capable of flowing is classified as light, medium, or heavy using this number. Light oil has an API gravity greater than 31.1° and a high paraffin to naphthene plus aromatic ratio. Medium oil has an API gravity ranging between 22.3° and 31.1°. Heavy oil has an API gravity less than 22.3° and a high aromatics plus naphthenes to aromatics ratio. Crude oil that cannot flow without being heated or diluted is called extra heavy oil or bitumen. It has an API gravity of less than 10° and is composed primarily of polycyclic aromatics and asphaltics. This oil is commonly chemically “upgraded” to an API gravity of 31° to 33° and classified as synthetic crude oil.

In addition to API gravity, crude oil is also generally classified by its sulfur content. Sweet oil has a low sulfur content, whereas sour oil has a high sulfur content. Combining these two measures, traditionally, crude oil is classified by its location and used as a benchmark for trading. West Texas Intermediate (WTI) is a benchmark crude oil that is very light, sweet high-quality oil. Brent Blend is another benchmark that is a mixture of 15 crude oils from fields in the Brent and Ninian systems of the North Sea oil province. It is also high-quality light oil with a low sulfur content. The OPEC Reference Basket is a weighted average of oil blends from all of OPEC (Organization of the Petroleum Exporting

Countries), including Saudi Arabia, Qatar, Libya, Algeria, Dubai, Indonesia, Nigeria, Malaysia, and others. Included in OPEC is Arab Light, a light sour oil from Saudi Arabia; Tapis, from Malaysia and the reference for light Far East oil; Minas, from Indonesia and the reference for heavy Far East oil; Bonny Light oil from Nigeria; Saharan Blend from Algeria; and Tijuana Light from Venezuela, among others.

The U.S. Environmental Protection Agency (EPA) has another system to classify crude oil that has been released to the environment in a spill response scenario.

- **Class A: Light, Volatile Oils** are highly fluid, commonly clear oils that spread on water, have a high evaporation rate, a strong odor, and are usually flammable. They include most refined hydrocarbon products (distillates) as well as the highest quality crude oils. Class A oils penetrate soil and sand and may persist there under certain conditions but are easily removed with water. They may be toxic to humans, fish, and other biota.
- **Class B: Non-Sticky Oils** are waxy and oily. They include medium to heavy paraffin crude oils. Class B oils adhere firmly to surfaces but may be removed through vigorous flushing. Normally, they do not penetrate sand and soil well, but as temperatures rise penetration increases, as does persistence. They are less toxic than Class A oils, but evaporation from volatiles from Class B oils forms residues of Class C or D oils.
- **Class C: Heavy, Sticky Oils** are tarlike, sticky, and black to brown in color. They include residual fuel oils and medium to heavy crude oils. If left to evaporate, they produce class D oils. The oil does not easily penetrate porous materials, but it is nonetheless difficult to remove. It is heavy and can sink in water in some cases. These oils are not particularly toxic, but they can smother wildlife.
- **Class D: Nonfluid Oils** are black to brown and tarlike. They include residual oils, heavy crude oils, and high-paraffin oils. They do not penetrate porous materials, but, if heated, they melt onto surfaces and are very difficult to remove. Class D oils are relatively nontoxic.



Crude oil is refined into common petroleum products, including fuels, at an oil refinery. Primary refining is done through distillation in a distillation tower. The crude oil is heated at the base of the tower until it vaporizes. The vapor stratifies in the tower by its density, the lighter organic compounds floating to higher levels. It is condensed at several levels and collected as separate products: jet fuel at the top, diesel and gasoline in the middle, and tar at the bottom. These primary products may be modified into the other petroleum products as needed, using chemical catalysts. These catalysts may be used to break long hydrocarbon chain molecules into shorter ones (cat cracking) or they may be used to combine short chains into longer ones.

### FUEL OIL

Fuel oil is a product from the refining of crude oil. In strict terms, fuel oil is liquid petroleum that is used in an engine to generate power or in a furnace to generate heat. However, it typically only refers to the heaviest commercial fuels and does not apply to gasoline or other light fuels. The classification of fuel oil is in six grades based upon boiling point, composition, viscosity, and use. The oils are heavier and thicker for higher grades. Grades 1 and 2 are called distillate fuel oils whereas grades 4, 5 (light), 5 (heavy) and 6 are termed residual fuel oils (RFO).

- **Grade No. 1 fuel oil** is a light distillate that is similar to kerosene and slightly heavier than gasoline. It is highly volatile and used in vaporizing-type burners.
- **Grade No. 2 fuel oil** is diesel fuel used in trucks, cars, and some trains and is sometimes called road diesel. It is also called heating oil because it is the fuel used in home furnaces as well as many commercial-industrial burners. There is a dewaxed version of grade no. 2 available that is used in cold areas where regular grade no. 2 fuel oil would jell. It can be referred to as Bunker A fuel or marine gas oil (MGO).
- **Grade No. 3 fuel oil** is a distillate fuel that is rarely used.
- **Grade No. 4 fuel oil** is an intermediate fuel that can be a blend of distillate and residual fuel oils or just be a heavy distillate/light residual. It is too heavy to be used in home furnaces. It is sometimes referred to as Bunker B fuel.
- **Grade No. 5 fuel oil** is divided into light and heavy, depending on the climate in which it is to be used. It has an intermediate viscosity but still may require preheating in colder climates before it can be burned or even handled. It is also called Bunker B fuel or navy special fuel oil.
- **Grade No. 6 fuel oil** is an RFO that is sometimes called Bunker C, furnace fuel oil (FFO), heavy fuel oil (HFO), or marine fuel oil (MFO). It is mostly used in industrial heating but requires heating before pumping or burning.

Fuel oil is spilled into the ground surface and marine environments on a regular basis through normal handling as well as spills. Most shipping and boating accidents also involve the release of fuel oil into marine environments. The EPA classification for spilled crude oil also includes fuel oil, primarily as to their distillate or residual origins.

### VOLATILE ORGANIC COMPOUNDS (VOCs)

Any organic compound with vapor pressure that exceeds 0.002 pounds per square inch (0.133 mbar or 0.1 mm of Hg) at standard temperature and pressure is considered a VOC. They are characterized by low molecular weights, high vapor pressures, and a hydrophobic nature. They are commonly in the form of liquids and gases but rarely solids as well. Their volatility makes them very common atmospheric pollutants but less likely water and soil pollutants. The most common health effects from exposure to VOCs are eye and throat irritation, headaches and dizziness, nervous system damage, exacerbation of asthma and COPD (chronic obstructive pulmonary disease), and possible cancer.

Massive amounts of VOCs are constantly being released to the atmosphere through industrial processes and even regular human activities. Crude oil and fuels readily evaporate whenever exposed to the air. Solvents in paints and other surface coatings, as well as those used for cleaning, evaporate into the atmosphere as well. The inundation of the atmosphere by VOCs is not only a problem in itself, but VOCs also participate in a photochemical reaction with nitrogen oxide to produce low-level ozone, one of the most damaging air pollutants. Recent regulations limit the amount of VOC in household products because of the direct health effects. Considering the amount of VOC in the atmosphere today in comparison with the atmosphere of the past that contained essentially no VOCs, there may be more

### CHARACTERISTICS OF FUEL OIL

Grade No.	API Gravity	Density lb/gal	Higher Heating Value Btu/gal
1	38–45	6.950–6.675	137,000–132,900
2	30–38	7.296–6.960	141,800–137,000
4	20–28	7.787–7.396	148,100–143,100
5 (light)	17–22	7.940–7.686	150,000–146,800
5 (heavy)	14–18	8.080–7.890	152,000–149,400
6	8–15	8.448–8.053	155,900–151,300

dangerous effects that have yet to be realized. Common chemical groups of VOCs include alkanes, alkenes, aryl hydrocarbons, aldehydes and ketones, alcohols, epoxides, carboxylic acids and phenols, ethers, halogenated hydrocarbons, and nitrogen-containing organic compounds.

#### SEMIVOLATILE ORGANIC COMPOUNDS (SVOCs)

A semivolatile organic compound (SVOC) is an organic compound that has a low to moderate vapor pressure, so it can vaporize like a VOC but only at elevated temperatures. They have boiling points greater than that of water. SVOCs are hydrophobic and preferentially distribute to organic materials such as organic carbon in sediment and lipids (fat) in animal tissue. For that reason, they tend to bioaccumulate in animals and humans, but not to the degree of many other compounds, such as persistent organic compounds. Bioconcentration factors for SVOCs are typically between 10 and 1,000. This bioconcentration means that consumption of seafood and even some meats and homegrown vegetables can form ingestion pathways for SVOCs as can incinerator emissions, contact with contaminated soils and sediments, and contact with waste materials.

There are many SVOCs, including the numerous polycyclic aromatic hydrocarbons (PAHs), phenols, halogenated compounds, phthalates, azaarenes, nitrogenated compounds, and cyclic ketones, among others. Several of these are regarded as priority pollutants by the EPA and have been banned since the 1970s, named specifically in the Clean Water Act of 1977. Included among these are phthalates, phenols, and PAHs, which are probable human carcinogens and endocrine disruptors.

A long-term study by the U.S. Geological Survey found that SVOCs are nearly ubiquitous in sediments within streambeds of the United States and concentrated in urban areas. The study found that

the Northeast and the Great Lakes regions are particularly enriched. PAHs and phthalates were about 10 times higher in areas influenced by urban activities, and adverse health effects as a result are probable in 7.5 percent of these areas and possible in 16.2 percent.

#### SYNTHETIC ORGANIC COMPOUNDS (SOCs)

Sometimes known as non-VOCs, synthetic organic compounds (SOCs) are high-molecular-weight organic compounds that mostly exist as solids or high-boiling-point liquids (low vapor pressure). SOCs are released from industry or purposefully during regular activities. They enter the natural environment dissolved in precipitation, from fallout or dry deposition, through photochemical reactions, incorporated in particulate matter, and by uptake in plants.

The most dangerous of the SOCs are the persistent organic pollutants (POPs). These chemicals are released by industry or applied to agricultural settings and resist natural breakdown. That is why they are persistent. As a result, they have the ability to be transported long distances both in the atmosphere and in water. In many cases, POPs have been found in areas far from their points of release, such as in arctic ice. They also bioaccumulate and biomagnify through the food chain through this resistance. Bioconcentration factors for POPs range between 1,000 and 100,000, which are among the highest for any compound.

POPs are primarily insecticides, industrial chemicals, and the by-products of manufacturing processes and combustion. These include the most infamous of the insecticides, such as DDT, aldrin/dieldrin, chlordane, endrin, heptachlor, and toxaphene, among others. The industrial chemicals and by-products are equally infamous, including dioxin, PCBs, and furans. These compounds are extremely damaging

to the environment and even to human health. They are possible to probable human carcinogens and damage the kidneys, lungs, pancreas, nervous system, immune system, and endocrine system.

It is for these adverse health effects that there have been several national and international legislative actions to limit or ban several of the POPs. The 1989 United Nations Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal is an international agreement signed by 158 parties as of 2003 that includes POPs in the list of controlled substances. The 1998 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade is a succeeding international agreement that had 73 signatories by 2003 and was more specific to controlling POPs. The most direct and effective agreement, however, is the 2001 Stockholm Convention on Persistent Organic Pollutants (POPs) that had 151 signatories by 2003. This convention aims to eliminate or restrict production and use of all POPs and, ultimately, to eliminate accidental releases of industrial POPs, especially dioxin and furans. PCBs are to be completely eliminated by 2025.

### PPCPs AND EDCs

A relatively new group of organic pollutants of concern are pharmaceutical and personal-care products (PPCPs) and endocrine-disrupting compounds (EDCs). Although both have been in the environment for many decades (approximately 70 years), concern for their ubiquitous presence has recently become an area of great interest. The reason for this concern is because recent surveys have found trace levels of EDCs and PPCPs in most public water supplies and many surface waters and private water supplies. Even at trace concentrations, they can have ecological impacts. The problem is that most standard drinking water and wastewater treatments do not remove EDCs and PPCPs. New advanced treatments are being tested to address these shortcomings.

PPCPs are consumer bioactive chemicals, such as prescription and over-the-counter drugs, veterinary drugs, fragrances, cosmetics, sunscreen products, diagnostic agents, and nutraceuticals (vitamins) that have been released into the natural environment. The sources of such waste are human activity, pharmaceutical manufacturing, hospital waste, illicit drugs, veterinary waste, and agribusiness, among others. PPCPs have only been recognized as a threat by the scientific community since the 1970s, when they were found in trace amounts in treated municipal wastewaters. They were only recognized as a problem by the

U.S. government since 2007. The long-term impact of low-level exposure to PPCPs has yet to be determined, but the rapid development of drug-resistant bacteria is certainly exacerbated by their presence.

EDCs are synthetic, and even some natural, compounds that mimic the natural hormones in the endocrine systems of animals. By mimicking these hormones but not serving the required function in the body, they disrupt the homeostasis, reproduction, development, and/or behavior of the animal. There are three major classes of EDCs: (1) estrogenic, which mimic or block estrogen; (2) androgenic, which mimic or block testosterone; and (3) thyroidal, which directly or indirectly affect the thyroid. The primary area of research on the effects of EDCs is in reproduction. It was found that the EDC and pesticide DDT affected reproduction of birds and alligators; tributylins from antifouling paints and PVC pipes impacted marine gastropods; and the herbicide atrazine greatly affected the reproduction of frogs, among many others. Perhaps the most concerning finding, however, is that fish in the released treated water from wastewater treatment plants showed dramatic reproductive problems. This shows that the numerous wastewater treatment plants in the United States and the world are not removing the EDCs. There is no question that humans are being exposed to EDCs.

### MISCELLANEOUS ORGANIC POLLUTANTS

There are also several organic pollutants that have nonindustrial origins. One such pollutant is farm and stockyard waste. In most cases, livestock and farm animals are raised in tight quarters designed to maximize production. These animals are kept in high-density dwellings that result in issues with the disposal of large quantities of animal waste. In many areas, the waste is stored in shallow lagoons on the property. The massive quantity of stored waste is a problem in itself in terms of odor, local soil and water pollution, and disease. During storms, however, these lagoons can overflow and pollute surface water bodies. The waste can cause eutrophication of these bodies as well as spreading disease.

Stockyards are not the only source of such organic waste. Overflowing sewers and septic systems are also sources of high organic pollutants. They cause the same problems as stockyard waste but in a less concentrated manner.

*See also* AGRICULTURE AND POLLUTION; AIR POLLUTION; ALDRIN/DIELDRIN; ANTIFOULING PAINT; ATRAZINE; BIOACCUMULATION AND BIOMAGNIFICATION; CHLORDANE; DDT; DIOXIN; ENDRIN; EUTROPHICATION; FURAN; HEPTACHLOR; INOR-

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**ozone** There are two types of ozone, good ozone and bad ozone. Good ozone is located in the stratosphere in the range of about 10–30 miles (16–48 km) elevation above the surface of the Earth. This layer is good because it shields the surface from damaging ultraviolet radiation. Bad ozone is located in the troposphere and especially at elevations of less than 10 miles (16 km). It is this bad ozone that is the primary component of smog and the cause of health alerts in many cities around the world, as well as reduction in crop yield. It is also a greenhouse gas, contributing to global warming. Bad ozone can also be beneficial. It helps to cleanse other pollutants from the air such as hydrocarbons, hydrogen sulfide, and carbon monoxide, which would otherwise poison us. It is odd that a single substance can have such opposing functions. This dual ability is based on the chemical properties of ozone.

### PROPERTIES AND FORMATION

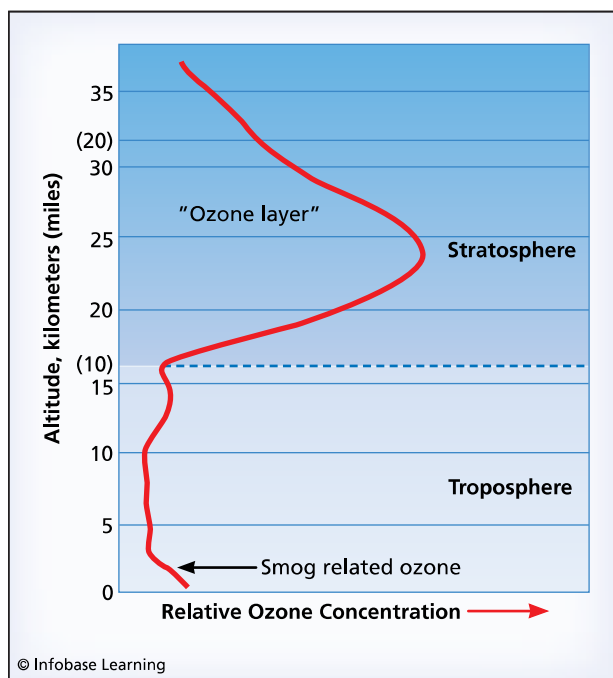
Ozone is a pale blue gas with a faint odor. Normal oxygen in the atmosphere is O<sub>2</sub>, and ozone is simply O<sub>3</sub>, but it is much less stable. Ozone was first identified as a compound in 1840, and it has actually

been monitored in Europe since about 1870 with a simple chemical test. It is both naturally occurring and anthropogenic. Ozone is produced by lightning strikes through dissociation and recombination of normal oxygen by the electrical discharge. It is similarly produced during electrical generation at power plants, as well as electrical use in many industrial and residential applications. In general, the more power-consuming the application, the more ozone is produced. This source of environmental ozone, however, is minor in comparison to other sources. The largest source of tropospheric ozone results from a complex series of photochemical reactions among nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOCs).

Nitrogen oxides are primarily produced by the burning of fossil fuels. By far, the primary sources of NO<sub>x</sub> are motor vehicles, with 56 percent of the production, followed by electric utilities and power generation (22 percent); industrial, commercial, and residential fuel combustion, including heating systems (17 percent); and all other sources of combustion (5 percent). VOCs are produced naturally by some trees, but they are primarily anthropogenic. The synthesized VOCs are almost exclusively produced from the refining and use of petroleum and the use of petroleum products. The primary source is the industrial and commercial production and processing of VOCs (50 percent), followed closely by the release of unburned hydrocarbons by motor vehicles, as well as evaporation of fuels (45 percent). The remaining 5 percent is produced by the evaporation of consumer solvents including paints, sealants and coatings, and cleaners. The number of motor vehicles in the United States increased from 142.1 million in 1977 to 189.4 million in 1993, and the burning of fossil fuels on a worldwide basis tripled in 40 years, thereby increasing both VOCs and NO<sub>x</sub>. When these substances that are pollutants in their own right are released into the atmosphere, they can be exposed to sunlight. The heat and ultraviolet radiation drive a complex series of dissociation reactions that ultimately produce ozone. The production is limited by the quantity of the reactants and the amount and strength of solar radiation. Summer months with minimal wind circulation and strong sunshine are the best conditions for ozone formation.

Bad ozone has some practical applications. Being a strong oxidizer, ozone has the capacity to sanitize, deodorize, and sterilize both water and air. Ozone generators sterilize the air in hospitals and purify air in homes in filtration systems. Ozone can remove microorganisms from meat and poultry and even reduce pesticides from fruits and vegetables. Ozon-





**Graph of relative ozone concentration in air versus altitude. The lower, tropospheric ozone is “bad ozone” in smog, and the stratospheric ozone is “good ozone” that filters ultraviolet (UV) radiation from the Sun.**

ated water is used in laundries, hot tubs, aquariums, and fish ponds. Ozone is used to sanitize municipal water supplies, because it leaves no residues, but it must be supplemented with chlorine because the water can support microorganisms after the ozone dissipates.

### ENVIRONMENTAL RELEASE AND FATE

The concentration of ozone in air from natural sources is about 10–15 parts per million (ppm), as measured in 1870. On average, between 1900 and 1970, the air in the United States experienced increases in the levels of ozone precursor NO<sub>x</sub> of 690 percent and of VOCs of 260 percent. As the result of industrialization, several regions of the United States have average concentrations of up to 125 ppm in summer months. It is not only urban areas of the country that have ozone pollution problems. Elevated ozone levels even exceeding those in the cities may extend downwind of these urban areas for hundreds of miles. Elevated ozone levels have been found in the Maine woods and the mountains of New Hampshire and New York. There is a continuous strip from central Virginia to eastern Maine, including the entire states of Connecticut, New Jersey, and Rhode Island, where the ozone levels consistently exceed the U.S. Environmental

Protection Agency (EPA) limits. There are numerous other counties peppered throughout the eastern United States (32 nationwide) that, in 2004, the EPA designated as in “nonattainment.” The states with the most counties in this designation are Pennsylvania, Maryland, Massachusetts, North Carolina, Michigan, Ohio, New York, Indiana, Tennessee, and Georgia, among others. In the West, a large swath of California is in nonattainment, as are the counties around Denver, Colorado; Phoenix, Arizona; and Houston and Dallas, Texas. Seven of the top eight highest-ozone metropolitan areas were in California, led by Los Angeles, in the 2004 ratings. It is estimated that three-quarters of the population of the United States resides in areas with excessive amounts of ozone in the air.

Vegetation is strongly affected by elevated ozone levels. It enters the plants by infiltrating leaves through the stomata during regular gas exchange. Ozone is a strong oxidant and, as a result, causes chlorosis and necrosis of the plants. Some of the symptoms of ozone poisoning include small (less than 0.04-inch [1-mm]) spots, called flecks; 0.08- to 0.16-inch (2- to 4-mm) darkly pigmented patches, called stipples; as well as bronzing and reddening of the leaves. These symptoms typically occur on tops of older and middle-aged leaves, but the severity is dependent upon the plant species. This damage reduces photosynthesis, cellular energy production, and the number of flowers and fruit. In addition to killing the plant directly, ozone may weaken the plant against pests, drought, and disease. Ozone not only damages trees and wild plants, but also damages crops. Research on crop damage from ozone has been carried out for nearly 40 years. It has been shown that dicot species such as soybeans, cotton, and peanuts start to suffer at as little as 20 parts per billion (ppb) of ozone and can have a 40 percent drop in yield at 100 ppb. Tobacco is even more sensitive. Some monocot species, however, such as sorghum and corn, are relatively resistant to ozone and do not show any effects until 60 ppb and even at 100 ppb only suffer a 10 percent drop in yield. Crop losses from ozone damage are estimated at \$500 million per year.

### HEALTH EFFECTS FROM EXPOSURE

Ozone is also toxic to humans, producing numerous adverse health effects. Up to 20 percent of healthy people are much more susceptible to the effects of ozone than the general population. It oxidizes the surface of the respiratory system, causing excessive mucus production and constriction of the muscles. Initial symptoms include coughing, throat irrita-

tion, wheezing, discomfort in the chest, and possible nausea. The National Institutes of Health reported a 5–10 percent reduction in lung capacity of people who exercised for 6.5 hours while exposed to 80 ppb of ozone. With prolonged exposure at high dosage, ozone may cause reduced lung function, aggravate chronic lung diseases and asthmatic conditions, inflame and damage lung tissue, and damage the immune system in the lungs, increasing the likelihood of bronchitis and pneumonia. Chronic exposure to ozone causes permanent damage to the lung tissue, decreased pulmonary function, and, ultimately, premature death. There are five groups of people who are at particular risk from the effects of ozone: people who have respiratory disease, older adults, people who work or exercise outdoors, children, and ozone-sensitive people. Approximately one-third of Americans are in this high-risk group including 27.1 million children and more than 1.9 million children who have asthma. It was found that each increase of 20 ppb of ozone in air was associated with a 63 percent increase in school absence due to illness and an 83 percent increase in respiratory illness. The children at greatest risk are disproportionately members of minority groups.

A recent study in Europe found that during the summer, an increase in ozone of one hour resulted in an increase in the total daily number of deaths of 0.33 percent, of death by cardiovascular failure of 0.45 percent, and death by respiratory failure of 1.13 percent. This study indicates that even short-term exposure to ozone can be deadly.

### REGULATIONS ON HUMAN EXPOSURE

In 1971, the EPA set the limit of ozone in ambient air at 120 ppb averaged over an eight-hour day under the newly enacted Clean Air Act. In 1997, the limit was revised to 80 ppb. For an area to be in compliance, the fourth highest eight-hour concentration in one year, averaged over a three-year period, cannot exceed 80 ppb. In addition, areas cannot exceed 120 ppb for a period of one hour more than once over any three-year period. This new limit made many areas out of compliance. On days when ozone is in excess of the limit or expected to exceed the limit, an Ozone Action Day may be declared, in which restrictions on exposure and vehicle use may be imposed. It is monitored through the state and local air monitoring network stations (SLAMS) and national air monitoring network stations (NAMS), among others. The World Health Organization recommends a maximum of 60 ppb averaged over any eight-hour period for a maximum of 20 days per year. In Canada, the maximal concentration is 50 ppb averaged

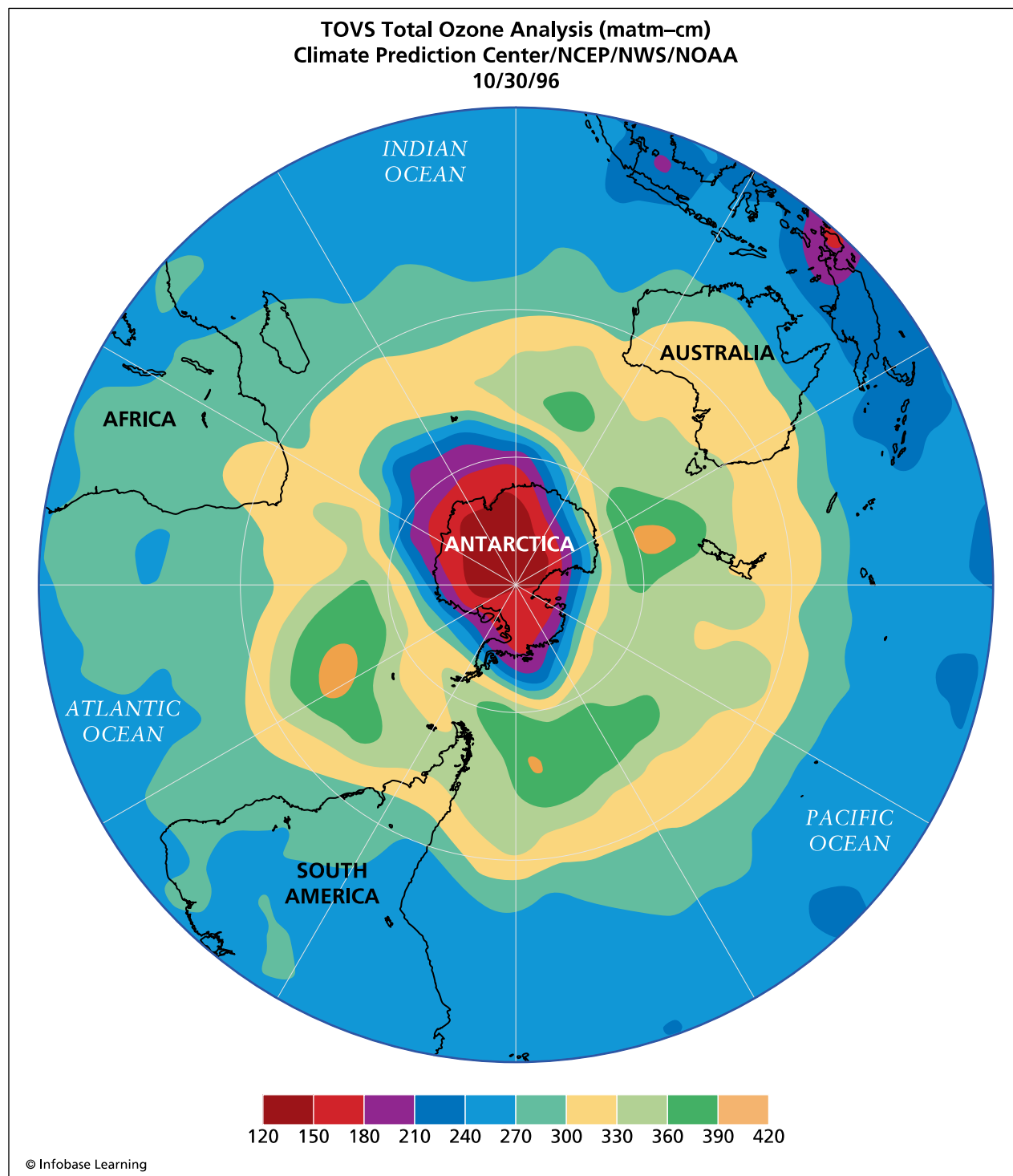
over eight hours. The good news is that the legislation appears to be working. On average, the ozone in American cities decreased from about 130 ppb in 1988 to 105 ppb in 1997. In contrast, ozone around cities in China is greatly increasing, with projected levels 25 percent higher than today's by 2050.

See also AIR POLLUTION NO<sub>x</sub>; OZONE AND CHLOROFUOROCARBONS; VOLATILE ORGANIC COMPOUND.

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**ozone and chlorofluorocarbons** Ozone is elemental oxygen that has been changed from its most stable form, diatomic oxygen, or O<sub>2</sub>, to the much more reactive form, triatomic oxygen, or O<sub>3</sub>. It is formed naturally in the upper atmosphere, the lower part of the stratosphere, as ultraviolet light from the Sun energizes floating oxygen molecules. This causes some of the O<sub>2</sub> molecules to break apart



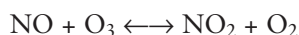
**South Polar projection of the Earth with the density distribution of stratospheric ozone superimposed on it. A large “hole” in the ozone layer appears over the Antarctic as the result of destruction by chlorofluorocarbons (CFCs).**

and then rejoin to form  $O_3$ . Ozone also can be formed when an electrical current discharges through the air, such as during a lightning storm. The energy released by the spark causes oxygen in the air to break apart, with a portion of it re-forming as ozone.

Physically, ozone is a pale blue gas with a sharp odor, often present in the air after a thunderstorm or near an old or failing electric motor. At  $-170^\circ\text{F}$  ( $-112^\circ\text{C}$ ), ozone condenses to a dark blue liquid, and it freezes at  $-315^\circ\text{F}$  ( $-193^\circ\text{C}$ ). The main char-

acteristic that makes ozone a very useful material and a significant air pollutant is its reactivity. Ozone is a powerful oxidizing agent, much more so than  $O_2$ . It can break apart many different types of organic compounds and is used as bleach for waxes, oils, and textiles. It also is a strong deodorizing agent and effective germicide, used to sterilize air and drinking water. Commercial manufacture of ozone is done by passing an electrical current through  $O_2$  or dry air; the end product of ozone and  $O_2$  or ozone and air is suitable for most industrial applications.

The ozone that forms by natural atmospheric process is also not very stable. The energy present in the ultraviolet rays that initially broke apart the  $O_2$  and allowed the ozone to form also strikes the larger  $O_3$  molecule, splitting it up once again into single oxygen atoms and double oxygen molecules. Ozone also is destroyed through its chemical interaction with nitric oxide (NO), which is naturally present in the atmosphere. NO forms when nitrous oxide ( $N_2O$ ), a relatively inert gas, floats up through the troposphere and enters the stratosphere. Once  $N_2O$  is in the stratosphere, it reacts with oxygen atoms that are excited by ultraviolet rays to form nitric oxide. The nitric oxide then combines with ozone to form nitrous oxide and oxygen:



As Earth's atmosphere evolved, the processes that created and destroyed ozone eventually reached equilibrium. If the amount of ultraviolet radiation from the Sun increased, the concentration of ozone in the stratosphere also increased. As ultraviolet activity weakened, ozone concentrations began to drop. The final outcome of this balance was the formation, within the Earth's atmosphere, of a comparatively thin zone, or band, more popularly known as the ozone layer, where ozone is formed and destroyed. It is about 13 miles (21 km) thick, but even within this band, ozone is rare. For every 10 million molecules of air in the lower stratosphere, there are only three ozone molecules. If all the ozone in this 13-mile- (21-km-) wide band were compressed, it would form a layer about as thick as a dime.

As sparse as it is, ozone plays a vital role in shielding the Earth's surface from the Sun's dangerous ultraviolet radiation. Its presence is as vital to our long-term health and quality of life as reliable sources of clean water. Ozone level is a global issue, threatening our very survival on the planet, when not enough ozone is present in the stratosphere.

The creation of ozone acts as an effective filter or barrier for the ultraviolet radiation that is constantly

bombarding the Earth from the Sun. This ultraviolet radiation is very energetic and, if left unchecked, can damage or destroy most tissue of plants and animals. Normal diatomic oxygen filters most high-level ultraviolet radiation, that with wavelengths shorter than 240 nm. It is the absorption of this radiation that causes it to break, or change  $O_2$  molecules into single oxygen atoms (O). There is a large amount of ultraviolet radiation with wavelengths between 240 nm and 290 nm that  $O_2$  cannot absorb. It is this longer-wavelength ultraviolet radiation that is absorbed by the ozone layer, providing the energy for the temporary joining of  $O_2$  molecules and O atoms into  $O_3$ .

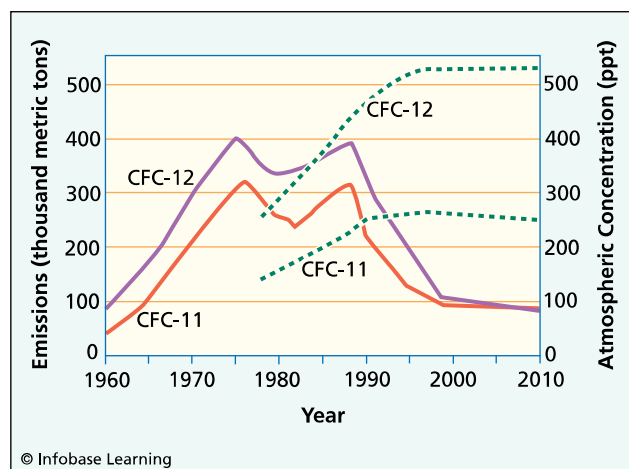
### DEVELOPMENT OF CFCs

Refrigerators and refrigeration systems were introduced in the late 1800s and by the 1920s were common household appliances. Early refrigerators were kept in the yard or back porch because, until 1929, the coolant was a toxic gas, usually ammonia ( $NH_3$ ), methyl chloride ( $CH_3Cl$ ), or sulfur dioxide ( $SO_2$ ). It was not uncommon, in the early 1920s, for entire families to be asphyxiated by a coolant leak from their refrigerator. In response, the three principal makers of refrigerators at the time—Frigidaire, General Motors, and DuPont—joined to develop a less dangerous method of refrigeration. By 1928, they had an answer. A chemist with General Motors, Thomas Midgley, Jr., developed a “miracle compound” and named it Freon.

Quickly patented by DuPont, Freon was the first of a class of chemicals called chlorofluorocarbons, or CFCs. They are aliphatic organic compounds containing carbon and fluorine and, in other formulations, halogens and hydrogen. Colorless, odorless, nonflammable, nontoxic, and noncorrosive, CFCs are chemically nonreactive and very stable. Their best feature is that their boiling point is close to room temperature (77°F [25°C]), and they can be transformed readily from a gaseous to a liquid state, making them excellent coolants for refrigerators and air conditioners. In refrigerators, as liquids evaporate, they absorb heat, a process known as latent heat transfer. Freon and other CFCs evaporate at very low temperatures, and, as such, these substances can create cooling or freezing conditions very readily. Freon 14's boiling point is 78.8°F (23.8°C). They also have been used in fire extinguishers and as aerosol propellants, solvents, and foaming agents.

Freon is nontoxic and, therefore, eliminated the danger posed by refrigerator leaks. In just a few years, compressor refrigerators using Freon became





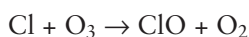
**Graph showing total emissions of CFC-11 and CFC-12 (solid lines), two of the most common CFCs, versus years from 1960 to 2000. There was a sharp decline in CFC emissions through the 1990s as the result of legislative actions on a global scale. Unfortunately, CFC concentrations in the atmosphere (dashed lines) continued to increase through this time as a result of previous releases. It will be several years before the concentration begins to decrease substantially. (Source: data from the U.S. Council on Environmental Quality)**

the standard for almost all home kitchens. In 1930, Thomas Midgley held a demonstration of the physical properties of Freon for the American Chemical Society by inhaling a lung-full of the new wonder gas and breathing it out onto a candle flame, which was extinguished, thus showing the gas's nontoxicity and nonflammability.

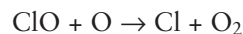
These miracle compounds are inexpensive to manufacture, long lasting, and inert. They were responsible for much of the modern conveniences of the 20th century and were used in numerous applications by almost every American on a daily basis. Every aerosol can used some form of CFC, as did every refrigerator and air conditioner. The cooling ability resulted in population shifts in the United States to southern areas that previously were underdeveloped because of their hot climate. As a result, CFCs became one of the highest-volume manufactured chemical groups in the United States.

### DAMAGE TO THE OZONE LAYER

It was only a few decades after CFCs were developed that scientists began to discover that they endangered the ozone layer and, with it, life on the entire planet. The reason that they are damaging to ozone is a result of the chlorine in the atom. Unattached chlorine atoms (Cl) break down ozone (O<sub>3</sub>) by the following reaction:



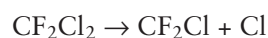
The chlorine is then regenerated when the ClO interacts with free oxygen atoms:



This cycle can continue for up to two years, the typical atmospheric lifetime for a chlorine atom, and during this time an average of 100,000 ozone molecules can be broken apart by a single chlorine atom. Eventually, the chlorine is removed from the atmosphere after it forms either hydrogen chloride or chlorine nitrate. These compounds tend to sink to the troposphere, where they are washed out by rain or other forms of precipitation.

Most forms of chlorine from bleach, swimming pools, industrial plants, seawater evaporation, and volcanoes do not reach the stratosphere. Chlorine from these sources combines with water vapor and is washed out of the troposphere. Only large fires and certain types of marine life can produce a stable form of chlorine that may reach the stratosphere. It is CFCs that make up approximately 85 percent of the chlorine in the stratosphere, and natural sources add the remaining 15 percent.

When those very stable and long-lived CFCs are released, they are able to reach altitudes well into the stratosphere, 15–25 miles (24–40 km) above the Earth's surface, without breaking down. There they undergo chemical reactions through exposure to ultraviolet radiation, which dissociates them, producing free chlorine atoms:



The free chlorine then participates in the ozone-consuming reactions described earlier. The behavior of chlorine in the atmosphere and its potential catastrophic effect on the ozone layer were first explained in 1974 by Mario Molina and F. Sherwood Rowland working at the University of California. They realized that CFCs could gradually make their way into the ozone layer and be broken down by ultraviolet radiation. Once liberated, the chlorine would begin to interact with and destroy ozone molecules. They presented a series of calculations demonstrating that if CFCs were to continue to be released at the current (1974) rate, the ozone layer would be significantly depleted in a few decades.

CFCs were valuable and useful industrial chemicals utilized around the world, and Molina and Rowland's prediction of a thinned ozone layer and worldwide adverse health effects caused a scientific sensation. Some researchers and climatologists attacked their methodologies, instrumentation, and calculations, whereas others began their own

## COMMONLY USED CFCs

Trade Name	Chemical Name	Usage
CFC-11 (Freon 11)	Trichlorofluoromethane ( $\text{CCl}_3\text{F}$ )	Used primarily as a propellant in aerosol sprays. Banned in the United States in 1978. Also used as a refrigerant, foaming agent for polyurethane foams, solvent and degreaser, and fire-extinguishing agent.
CFC-12 (Freon 12)	Dichlorodifluoromethane ( $\text{CCl}_2\text{F}_2$ )	Applications included use as a leak-detecting agent and in direct-contact food freezing. Widely used in restaurants and bars to chill or frost cocktail glasses and beer mugs. Many biological laboratories used this CFC to prepare frozen tissue sections. Used in manufacture of aerosols for cosmetics, pharmaceuticals, insecticides, paints, adhesives, and cleaners. Formerly, the main component of many home and commercial air-conditioning and refrigeration systems.
CFC-113 (Freon 113)	1,1,1-trichlorotrifluoroethane ( $\text{C}_2\text{F}_3\text{Cl}_3$ )	Chemical used in the manufacture of fluoropolymers. Also used in fire extinguishers and in the drying and degreasing of electronic parts and equipment. It is also commonly applied as a dry-cleaning solvent for all fabrics, leather, and suede. Also serves as a refrigerant in commercial or industrial air-conditioning and industrial process cooling systems.
CFC-114 (Freon 114)	Dichlorotetrafluoroethane ( $\text{C}_2\text{F}_4\text{Cl}_2$ )	Temperature-sensing agent, refrigerant, foaming agent, and aerosol propellant.
CFC-115 (Freon 114)	Chloropentafluoroethane ( $\text{C}_2\text{F}_5\text{Cl}$ )	Refrigerant and aerosol propellant.

experimental programs to try to confirm or repudiate Molina and Rowland's findings. Within a few years, there was widespread acceptance within the scientific community that Molina and Rowland were correct; several studies even found that they had underestimated the risk.

Even with the dire predictions, it took another 10 years and another startling scientific finding before the political systems finally recognized the danger. In 1985, scientists with the British Antarctic Survey, Joseph Farman, Brian Gardiner, and Jonathan Shanklin, published a paper describing an "ozone hole," or depletion in the stratosphere, over the Antarctic. The highest rates of depletion occur mainly over Antarctica and, to a lesser extent, the North Pole. These results formed the basis of a massive publicity and educational campaign by scientists and environmentalists aimed at policy makers and the public. The efforts led directly to the prohibition on the use and release of CFCs and other types of ozone-depleting chemicals.

For their pioneering work on upper atmosphere ozone chemistry, Molina and Rowland shared the 1995 Nobel Prize in chemistry with Paul Crutzen,

one of the world's leading researchers in mapping the chemical mechanisms that measure stratospheric ozone concentration.

## THE POLICY ON OZONE

In 1987, the United Nations brokered an international treaty called the Montreal Protocol that required most developed countries to stop using CFCs and banned all uses of the gases most dangerous to ozone by 1996. It will take time for the Montreal Protocol to have any real effect. Ozone-depleting gases are still making their way into the stratosphere, and it is likely that the ozone layer will continue to be stressed, as most models do not predict a turnaround until the early 2000s. It will be almost 100 years after that when the ozone layer will reach pre-CFC levels.

HCFCs (hydrochlorofluorocarbons) and HFCs (hydrofluorocarbons) are the chemicals being used to replace CFCs. They have less chlorine and are, therefore, less prone to react with stratospheric ozone. HCFCs and HFCs are ozone-depleting gases, but they are much less destructive than CFCs. The Montreal

Protocol requires that they, too, must be phased out by 2030. A more ozone-compatible replacement for these chemicals will have to be developed in the near future.

### HEALTH CONSEQUENCES

With a thinning ozone layer there is increased exposure to ultraviolet radiation (UVR). The most severe effect of that increased exposure is an upsurge in the rate of skin cancer. When UVR damages the deoxyribonucleic acid (DNA) in skin cells beyond the body's ability to repair them, the damaged cells begin to grow and multiply at an uncontrollable rate and a tumor (skin cancer) develops. Skin cancer generally, first, appears in the outermost layer of skin, the epidermis, allowing early detection of most skin cancers. The disease can be divided into two basic types, nonmelanoma skin cancer, which includes basal cell cancer and squamous cell cancer, and melanoma, as shown in the table.

Nonmelanoma skin cancers develop slowly and have very effective treatment regimens. They rarely

are fatal, although squamous cell cancers result in an estimated 2,200 deaths every year in the United States. At least 1 million cases of basal cell and squamous cell skin cancers are reported annually in the United States, more than double the number of diagnosed cases from 20 years ago. If not treated promptly, nonmelanoma skin cancers spread and become disfiguringly large. Although less common, malignant melanoma is far more dangerous. It accounts for about only 5 percent of the total number of skin cancer cases reported in the United States but causes 75 percent of skin cancer-related deaths. Some 54,000 new cases of melanoma are diagnosed each year, and about 7,800 people lose their lives to it despite improvements in diagnosis and treatment.

Higher levels of UVR also have other human health effects, including increased susceptibility to sunburn and premature aging of the skin. Other potential effects of increasing UVR concentrations, which are still being studied, may consist of eye damage such as inflammation of the cornea, forma-

### TYPES OF SKIN CANCER AND TREATMENT

Type	Description	Treatment
Basal cell carcinoma (also called epithelioma or basal cell cancer)	Forms in the basal cell layer, the innermost layer of the epidermis. Most common form of skin cancer. Many different appearances: red patch or irritated area; smooth, shiny, and waxy-looking bump; a white or yellow scarlike area; smooth reddish growth. Chronic exposure to sunlight is the cause of almost all basal cell carcinomas.	Basal cell carcinoma grows slowly and does not usually spread to other parts of the body (metastasize). Most common treatment is curettage and electrodesiccation—scraping away the tumor and then destroying a thin surrounding layer with heat. Other treatments include surgical excision and cryosurgery (freezing with liquid nitrogen).
Squamous (scaly) cell carcinoma	Develops in the cells of the epidermis that make keratin. Occurs most commonly on Sun-exposed parts of the body and develops over a long period. Mucus membranes, especially the lip, can also be affected.	Surgical removal is the most effective way to control this type of skin cancer. Lasers, cryotherapy (freezing), and topical medications can be helpful in very early, superficial stages. Radiation treatments are used for more advanced cases. When properly treated, the cure rate is high. Squamous cell carcinoma can grow quickly and, unlike basal cell, spread to other parts of the body.
Melanoma	Arises in the pigment-producing cells (melanocytes) of the skin. Appears as a new mole or on an existing mole or discoloration of the skin. It has the potential to spread to other sites or organs in the body. Accounts for only about 4 percent of all skin cancer cases; causes the majority of skin cancer-related deaths. The main cause is overexposure to ultraviolet radiation (sunlight).	Removal of the tumor is the treatment of choice for early-stage melanoma. In later stages of the disease, surgery is generally followed with chemotherapy, radiation, or immunotherapy. The chance of developing melanoma increases with age. It is one of the most common cancers in young adults and those who tend to sunburn easily. People who work outdoors or live in areas where sunlight is very strong (the American Southwest) are at higher risk.

tion of corneal lesions, and cataracts. Some evidence also points to UVR as an immune system suppressant.

See also AIR POLLUTION; CRUTZEN, PAUL; MOLINA, MARIO; NO<sub>x</sub>; OZONE; RADIATION; SULFUR DIOXIDE.

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# P

## **Pacific Gas & Electric Company Hinkley, California (1987–1997) Water Pollution**

Few environmental disasters are widely known by the public. Several of the major oil spills were recognized for a while after they occurred, such as the Santa Barbara oil spill in California the *Exxon Valdez* spill in Alaska, and nuclear disasters such as those at Chernobyl and Three Mile Island. These, however, were very important events with far-reaching consequences. Most less dramatic pollution episodes and sites, such as the more than 1,800 Superfund sites in the United States, are unnoticed by everyone except the local residents affected and regulatory agencies. An exception to this is the Woburn, Massachusetts, well G and H site, because it was made into a movie in 1998 titled *A Civil Action*. The Pacific Gas & Electric Company site in Hinkley, California, is even better known, as it was the subject of the 2000 film *Erin Brockovich*—the most commercially successful film about an environmental problem, with its leading actress, Julia Roberts, winning an Academy Award as “Best Actress” for her portrayal of the title role. This popularized event was the chromium contamination of a small town in California.

### **BACKGROUND**

Chromium is a dense, malleable metal that is steel gray in color. One of the main properties of chromium is that it can be polished to a high brilliance. Chromium also resists corrosion and has been added to steel and other metals to improve both their appearance and their performance under extreme conditions. Some of its first uses were in dyes and paints. Chromium is also a widely used dietary

supplement. It is an essential trace metal required for healthy mammalian metabolism. In its trivalent form, chromium, as does insulin, reduces blood glucose levels and can be used to control certain types of diabetes. In proper doses, chromium helps to lower low-density lipoprotein (LDL) cholesterol levels.

Chromium also has special electrochemical characteristics including three valence states: +2 (divalent), +3 (trivalent), and +6 (hexavalent). Trivalent chromium (+3) occurs naturally in the environment, and compounds of it are used for plating, in the formulation of dyes and pigments, in leather tanning and finishing, and in wood preserving. Trivalent chromium also is the form that is needed for the proper functioning of human and many other animal metabolisms. Hexavalent (+6) chromium is artificially manufactured and is used in combination with sulfuric acid and water in industrial metal plating baths and in leather tanning operations. Hexavalent chromium also can form during heating of other forms of the compound. Hexavalent chromium acts aggressively inside the human body. Breathing high levels can irritate or damage the nose, throat, and lungs. Irritation or damage to the eyes and skin also can occur if it contacts these organs in high concentrations or for a prolonged period. Repeated or prolonged exposure can damage the mucus membranes of the nasal passages and result in ulcers. In severe cases, exposure causes perforation of the septum, but this effect appears dose-related, and breathing small amounts of hexavalent chromium, even for long periods, usually does not cause respiratory tract irritation in most people. Some individuals become allergic to hexavalent chromium, so that inhaling the chromate compounds can cause asthma.

All forms of hexavalent chromium (dissolved in liquids, respirable dust, vapors, fumes, mists, etc.) are regarded as carcinogenic. The risk of developing lung cancer increases with the amount of hexavalent chromium inhaled and the duration of exposure. Studies of workers in chromate production, chromate pigment, and chrome electroplating industries employed before the 1980s, when current safety standards went into effect, show increased rates of lung cancer mortality. Certain hexavalent chromium compounds produced lung cancer in animals that had the compounds placed directly in their lungs.

### **POLLUTION OF THE SITE**

One of the more well-known examples of potential chromium exposure occurred in the small town of Hinkley, California (a population of about 1,900 as of this writing), located in the Mojave Desert, approximately 120 miles (192 km) northeast of Los Angeles. As part of its natural gas distribution system, in 1952, the Pacific Gas & Electric (PG&E) Company constructed and operated a gas pipeline that extended from Texas through most of California. Founded in 1905, PG&E is one of the oldest and largest public utilities in the United States, supplying gas and electricity to most of northern California. Associated with this natural gas pipeline were a series of large complex compressor stations. At about every 300 miles (500 km), the pressure in the natural gas pipeline needed to be increased to ensure its continued uninterrupted flow to commercial and residential customers. One of these compressor stations is just outside Hinkley. During repressurization of the gas, large amounts of heat are generated, and to dissipate this heat, PG&E ran water around and through the compressors. The hot water was then fed into a series of cooling towers and recycled through the compressors.

As part of the compressor station's routine equipment maintenance procedures, a rust inhibitor was added to the cooling water. This rust inhibitor contained hexavalent chromium as one of its main active ingredients. Over time, the cooling water became contaminated with small particles of grit and metal called undissolved or settleable solids. When concentrations of these solids reached a certain level, PG&E discharged the water into a series of unlined pits or settling basins. This practice went on until 1972, when changes mandated by the new California Regional Water Quality Control Board (RWQCB) regulations took effect and required that the settling basins be lined with an impervious material, such as clay or plastic. Lining the ponds reduced the likelihood that contaminants present in the cool-

ing water would infiltrate the soil from the ponds and enter the groundwater.

By then, it was already too late. PG&E had discharged an estimated tens of thousands of gallons of hexavalent chromium-contaminated water into the unlined ponds. This resulted in the contamination of the groundwater that the residents of Hinkley used for drinking, bathing, cooking, and filling their swimming pools. PG&E also used a spray aeration technique (jetting the water into the air) as a way to dispose of contaminated water. As this water evaporated, the settleable solids that had been floating in it became airborne as dust and particulate.

In 1987, PG&E notified the RWQCB that it had detected hexavalent chromium in several nearby groundwater wells. The reported concentrations were in the 0.6 part per million (ppm) range, above the federal MCL of 0.1 ppm, as well as the California standard of 0.05 ppm. As the investigation into the extent of contamination proceeded, PG&E, as did many corporations at the time, kept the findings of its environmental investigations secret and did not alert the residents of Hinkley that its public water supply contained hexavalent chromium. PG&E admitted years later that this was a mistake and that they should have promptly informed those people drinking the water of the presence of hexavalent chromium. Concerned over potential impacts to their health and property values, in the early 1990s, 648 residents of Hinkley joined in a class action suit against PG&E, spearheaded by the law firm of Masry & Vitoe, in combination with two other, much larger law firms, as well as Masry & Vitoe's flamboyant legal assistant, Erin Brockovich.

### **LAWSUIT AGAINST PG&E**

The basis of the class action lawsuit was that chronic (long-term) exposure to low levels of hexavalent chromium had resulted in a wide variety of illnesses and disabilities including uterine cancer, breast cancer, Hodgkin's disease, cancer of the brainstem, gastrointestinal cancer, miscarriages, nosebleeds, asthma, heart failure, damaged immune systems, and many other types of health problems. PG&E agreed to settle the case via private binding arbitration and not through a traditional public trial. During the arbitration process, medical and scientific experts for both sides presented evidence affirming and refuting the basis for the plaintiffs' health claims. Ms. Brockovich also procured a laboratory report that indicated that hexavalent chromium levels in one water supply well were in the 20-ppm

range, not the 0.6-ppm concentration claimed by PG&E. In 1997, PG&E settled the claims for \$333 million, one of the largest toxic tort judgments ever awarded in the United States.

The lawyers representing the plaintiffs took as their fee \$133 million. Ms. Brockovich received a \$2 million bonus. After \$10 million in expenses, the remaining \$188 million (about \$300,000 per individual) was distributed by the attorneys to the plaintiffs, on the basis of the severity of their illnesses. As part of the settlement, PG&E admitted no guilt or fault for damaging anyone's health, but they did agree to take full responsibility for the cleanup of the groundwater. PG&E passed along the costs of the Hinkley settlement to its customers but declared bankruptcy in 2001 in an electrical rate-fixing scandal that also contributed to the recall of the then California governor Gray Davis. Arnold Schwarzenegger was elected governor of California in his place. After a state-sponsored bailout of its finances, PG&E emerged from bankruptcy in 2004 under new management and continues to provide electricity and natural gas to the citizens of California, albeit at some of the highest rates in the country.

See also CHERNOBYL NUCLEAR DISASTER; CHROMIUM; EXXON VALDEZ OIL SPILL; GROUNDWATER; LOVE CANAL; SANTA BARBARA OIL SPILL; WOBURN WELLS G AND H.

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**PAH (polycyclic aromatic hydrocarbon)** Even though there is very little industrial production of PAH compounds, they are among the most widespread of the organic pollutants. They are primarily produced through incomplete burning of carbon-based compounds but also present in several common products. There are about 100 PAH compounds, and about 15–20 (depending upon the source) are considered to be significant health hazards. They include many of the following:

acenaphthene  
 acenaphthylene  
 benz(a)anthracene  
 benzo(a)pyrene  
 benzo(b)fluoranthrene  
 benzo(e)pyrene  
 benzo(k)fluoranthrene  
 benzo(j)fluoranthrene  
 dibenz(a,h)acridine  
 dibenz(a,h)anthracene, or anthracene  
 dibenz(a,j)acridine  
 dibenzo(a,e)pyrene  
 dibenzo(a,h)pyrene  
 dibenzo(a,i)pyrene  
 dibenzo(a,l)pyrene (pyrenes)  
 7H-dibenzo(c,g)carbazole  
 fluorene  
 indeno(1,2,3-cd)pyrene  
 5-methylchrysene, or chrysene  
 phenanthrene

They are also more commonly found in Superfund sites, and there is a greater likelihood of human exposure.

In the first 1,408 hazardous waste sites that the U.S. Environmental Protection Agency (EPA) assigned to the National Priorities List (Superfund sites), 600 were found to contain PAHs, although not all may have been evaluated for them. As a result of the widespread distribution and adverse health effects caused by exposure to PAHs, they were ranked the eighth most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

#### PROPERTIES AND USES

Pure PAH compounds are colorless, white, or yellow-green crystalline solids. Some are used in medicines, dyes, plastics, and pesticides, and others are used only in laboratory biochemical or biomedical research. Most PAHs are found in mixtures of other substances. At least eight of those listed are found in coal tar, which has a variety of applications from

treatment of skin ailments such as eczema and psoriasis in shampoo and ointments to fuel for steel industry furnaces. It is also used to make coal tar pitch and creosote. At least six of the listed PAH compounds are contained in coal tar pitch, which is used for aluminum production, roofing, and surface coatings, among other uses. At least two of the list are constituents in creosote, which is a common preservative for railroad ties, telephone poles, and pilings in marine areas and is sometimes used as fuel for steel production. At least three of the list are constituents in bitumens and asphalt, whose primary use is in paving but also in making objects soundproof and waterproof and in pipe coatings. Suppliers for the PAHs listed are few in number, ranging from two to 20.

### ENVIRONMENTAL EXPOSURE AND FATE

PAH is produced by incomplete burning of organic compounds. In general, PAHs occur in exhaust from gasoline and diesel engines, smoke from open burning, industrial smoke emissions, coal tar and pitch, coke oven emissions, asphalt, creosote, mineral oil, soot, tobacco and its smoke, and charcoal broiled foods. Benzo(a)anthracene is found in exhaust fumes, tobacco smoke, general soot and smoke, coal tar and pitch, amino acid, fatty acid, waxes, solvents, mineral oil, and creosote. Benzo(b)fluoranthene is also in exhaust, tobacco and its smoke, tar, soot, and amino and fatty acid pyrolysis. Benzo(j)fluoranthene is in exhaust, tobacco smoke, crude and used motor oil, and coal tar. Benzo(k)fluoranthene is in the same products as benzo(j)fluoranthene plus lubricating oil. Benzo(a)pyrene is in all of the general PAH sources and pyrolysis products of carbohydrates, amino acids, fatty acids, shale oil, and commercial solvents. Dibenz(a,h)acridine is in tobacco smoke condensate, coal smoke and soot, petroleum refineries, and incinerators. Dibenz(a,j)acridine has the same sources as dibenz(a,h)acridine. Dibenz(a,h)anthracene is in car exhaust, cigarette smoke, soot, and coal tar. The compound 7-H-dibenzo(c,g)carbazole is in cigarette tar. Dibenz(a,e)pyrene is in exhaust, fossil fuel, and tobacco smoke. Dibenz(a,h)pyrene is in exhaust, coal tar, and tobacco smoke, as are dibenzo(a,i)pyrene and chrysene, and dibenzo(a,l)pyrene is also in coal gasification products. Indeno(123-cd)pyrene is in exhaust, tobacco smoke, benzene and pyrene pyrolysis products, coal tar and pitch, and asphalt. The PAHs vary in amount of emissions to the environment. Some 1.8 million pounds (818,181 kg) of benzo(a)pyrene is emitted from stationary combustion sources, but 96 percent of it is from the weathering, processing, and burning of coal.

PAHs have various fates in the natural environment. They are mainly released to the air from forest fires, residential heating and burning, automobile and truck exhaust, and volcanoes. They enter surface water from industrial wastewater discharge, from wastewater treatment plants, and from air pollution fallout and washout from precipitation. They can be released to soil from industrial spills, dumping, leaks from hazardous waste sites, mining spoils, and air pollution fallout. In air, PAHs are typically vapors and adhere to particulate matter, where they can travel long distances before settling to the ground. The vapors are subject to photochemical breakdown and reactions with other atmospheric chemicals. In surface water, they also tend to bind tightly to particles and sediments and settle to the bottom or evaporate at the surface. They tend not to undergo significant biodegradation. A significant amount of the PAHs will also evaporate from the surface of soil. The rest will bind tightly to soil particles and largely remain fixed, with only small amounts leaching into the groundwater system. The dominant degradation process in soils appears to be the result of microbial activity. In aquatic and marine systems, PAHs tend to bioaccumulate significantly, especially in zooplankton and filter feeders.

### TOXICOLOGY AND HEALTH EFFECTS

Human consumption of PAHs is largely through smoking and consuming contaminated foods such as grilled meat and fish, as well as from air and water from contaminated areas. Acute exposure to PAHs can result in red blood cell damage and consequent anemia and immune system damage. Long-term chronic effects include reproductive problems and developmental problems. The real danger of PAHs, however, is that those described here are documented animal carcinogens and reasonably anticipated to be human carcinogens. Benzo(a)anthracene has produced cancer of the stomach, lungs, heart, kidneys, skin, and bladder and at injection sites in mice. Benzo(j)fluoranthene has produced skin and injection-site cancer in mice and pulmonary squamous cell carcinomas in rats. Benzo(a)pyrene has been shown to cause cancer of the skin in mice, rats, guinea pigs, hamsters, rabbits, newts, and subhuman primates and cancer of the lungs at injection sites. Cancer of the stomach, mammary glands, and brachial tubes were also commonly produced in mice, rats, and hamsters. Benzo(b)fluoranthene can induce skin tumors and local carcinomas. Dibenz(a,h)acridine and dibenz(a,j)acridine have been found to cause skin tumors and lung cancer in mice. Dibenz(a,h)anthracene has been shown to induce injection-



site sarcomas in rats, guinea pigs, pigeons, other fowl, and adult and newborn mice, including lung cancer from injection into lung tissues. Injection into the kidneys of frogs resulted in kidney cancer. Mice also experienced cancer of the forestomach, lungs, and mammary glands from general exposure. 7H-dibenzo(c,g)carbazole induced injection-site tumors in rats, respiratory tract tumors in hamsters from intratracheal injection, and forestomach tumors and hepatomas from general exposure in mice. Topical and injection exposure of dibenzo(a,e) pyrene, dibenzo(a,h) pyrene, dibenzo(a,i) pyrene, and 5-methylchrysene induced skin and injection-site sarcomas in mice.

Several studies suggest cancer in humans can result from exposure to PAHs. Exposures to coke oven emissions that contain mixed PAHs have been shown to cause increases in lung and urinary tract cancers in workers. Exposure to creosote that contains PAHs has been shown to cause skin tumors. Cigarettes, coal tar, coal tar pitch, and bitumens contain PAHs and are also associated with increased lung cancer, although there may be contributing factors. Skin contact with coal tar and shale oil, sources of PAHs, is associated with increased incidence in skin cancer.

### REGULATIONS ON HUMAN EXPOSURE

Several federal agencies have made recommendations and regulations regarding use, release, and exposure to PAHs. The EPA has provided suggested intake limits for PAHs for each 2.2 pounds (1 kg) of body weight, including 0.3 milligram of anthracene, 0.06 milligram of acenaphthene, 0.04 milligram of fluoranthene, and 0.03 milligram of pyrene. The only PAH that is regulated under the Safe Drinking Water Act is benzo(a)pyrene, at 0.0002 mg/L. The EPA further regulates the amount of environmental releases of PAH that must be reported to the National Response Center, including one pound (0.45 kg) for each of benzo(b)fluoranthene, benzo(a) pyrene, and dibenz(a,h)anthracene; 10 pounds (4.5 kg) for benz(a)anthracene; 100 pounds (45.5 kg) for each of acenaphthene, chrysene, fluoranthene, and indeno(1,2,3-c,d)pyrene; and 5,000 pounds (2,272 kg) for acenaphthylene, anthracene, benzo(k)fluoranthene, benzo(g,h,i)perylene, fluorene, phenanthrene, and pyrene. Coal tar exposure in the workplace is regulated by the Occupational Safety and Health Administration (OSHA), National Institute of Occupational Safety and Health (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH). OSHA established a limit of 0.2 mg of workplace air over an eight-hour-work-

day, 40-hour workweek. NIOSH's recommended exposure limit, time-weighted average (REL-TWA) is 0.1 mg per cubic meter of workplace air over a 10-hour-day, 40-hour workweek for PAHs in coal tar products. ACGIH sets a similar limit of 0.2 mg per cubic meter of workplace air over an eight-hour-workday, 40-hour workweek. Mineral oil exposure is also regulated by OSHA with a permissible exposure limit (PEL) of 5 mg per cubic meter of workplace air over an eight-hour-workday, 40-hour workweek; NIOSH sets a recommended exposure limit, time-weighted average (REL-TWA) of 0.1 mg per cubic meter of workplace air over a 10-hour-day, 40-hour workweek and a short-term exposure limit (STEL) of 10 mg per cubic meter of workplace air.

See also BENZENE; PARTICULATE; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE.

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**Parsons Chemical Grand Ledge, Michigan (1979–2018) Soil Pollution** In April 1945, a small agricultural chemical company named Parsons Chemical Works, Inc., opened on a 6.5-acre (2.6-ha) property in Grand Ledge, Michigan, about 100 miles (160 km) northwest of Detroit, just outside Lansing. Parsons was expert in the manufacturing of pesticides, herbicides, and solvents, as well as arsenic- and mercury-containing products. These compounds are used to control agricultural pests with the active ingredients dissolved in high-vapor-pressure solvents that quickly evaporate once applied to the crop or

soil, leaving the pesticide in place. The plant operated a successful, even at times thriving business for more than 30 years, until it closed in summer 1979.

### POLLUTION OF THE SITE

During site operations, Parsons flushed process residues, off-spec product, and wash water into floor drains inside its building. In modern agricultural chemical companies, these types of wastes, which can contain high concentrations of pesticides, mercury, arsenic, and chlorinated hydrocarbons, are captured by floor drains or in sumps that are connected either to the facility's own wastewater treatment system, a holding tank, or the municipal sewer system. At the Parsons facility, these floor drains were connected to a septic tank.

In the United States, almost a quarter of the population relies on septic systems to provide safe, effective treatment of household sanitary wastewater. In general, the waste pipe from a house or, in some cases, small office building, connects to a large 1,000 to 2,000-gallon (3,785–7,571-L) buried concrete basin that is divided into two chambers. As wastewater enters the first chamber of the basin, solids settle to the bottom, and greases and oils float to the top. Liquids then flow through portals in the wall separating the two chambers into the second chamber, where further settling and clarifying take place. Anaerobic bacteria in the basin organically degrade the solids and help to clarify the liquids.

Eventually, clarified liquids are discharged to a series of lateral pipes buried several feet below the surface. These pipes, often made of ceramic tiles and called a tile field, or leach field, are designed to release slowly or leak the liquids into underlying soil. Once released into the soil, the remaining organic impurities in the liquids are further degraded by bacteria in the soil or are taken up by plants. The size of the leach field is dependent on the volume of wastewater that it must receive, and higher flows require larger fields.

A less typical problem related to septic systems results from the introduction of organic chemicals such as paints, bleaches, dyes, or pesticides that destroy the essential anaerobic bacteria present in the tank and leach fields that are the mainstay of this sanitary wastewater treatment process. Without the bacterial degradation that takes place both in the septic tank and in the soil underneath the leach field, wastewater may just as well be poured directly onto the ground.

The Parsons septic system received pesticides, solvents, and heavy metal residues that probably rendered the inside of the tank bacteria-free. Once

liquid residues moved out of the tank, they entered a drain field, which, in turn, was connected to a catch basin in Eaton County's storm-water drainage system. During periods of high-volume flows, liquid wastes not discharged into soil underlying the leach field moved through the catch basin, which emptied to an unnamed tributary northwest of the plant that eventually connected to Grand River. At some point during the operational life of the facility, soil covering the drainage pipes (tile field) eroded away, and liquid wastes simply ran down the bank of the unnamed stream, contaminating the underlying soil and directly entering the surface water system.

Parsons also dumped pesticide and solvent residues onto the soil surrounding the southern side of its building. Eventually, an entire acre became contaminated. Groundwater is present within 10 feet (3.1 m) of the surface at the Parsons property, and soils are very permeable, allowing ready migration of contaminants into the underlying water-bearing zone. The area surrounding the Parsons site is a mix of commercial and residential uses. The city of Grand Ledge (population 11,000) provides potable water to its citizens from municipal supply wells about three miles (4.8 km) from the site, and a number of small businesses and private homes in the vicinity of the Parsons plant rely on individual wells to meet their water supply needs.

As the nationwide hazardous waste regulations of the mid-1970s began to take hold, the operators of the Parsons facility must have realized what was in store for them because in 1979 they sold the business to ETM Enterprises, Inc. (ETM), a fiberglass manufacturer. Concerns over environmental quality at the site led to a request by the Michigan Department of Environmental Quality (MDEQ) that ETM perform some soil and groundwater sampling. It was during this investigation that the connection between the septic system and storm-water catch basin was discovered, and ETM and MDEQ began to realize quickly that a serious environmental problem was probably present on the property.

MDEQ, the Eaton County Health Department, the U.S. Environmental Protection Agency (EPA), and ETM all began a series of investigations designed to identify the magnitude and extent of the soil and groundwater contamination thought to be present on the Parsons site. By the mid-1980s, these studies had found that surface and subsurface soils, sediments in the unnamed stream, as well as sediment in Grand River were contaminated with pesticides including dieldrin, chlordane, dichlorodiphenyltrichloroethane (DDT) and its breakdown products, organic compounds, and inorganic compounds including mercury, arsenic, and chromium.

### THE CLEANUP

In 1984, the site was included in the National Dioxin Study. This was a two-year evaluation of approximately 1,000 pesticide manufacturing, formulation, and use facilities that was mandated by the U.S. Congress. Its objective was to determine the extent of dioxin in soil, water, and the local ecology including fish and other wildlife and was motivated by high-profile contamination incidents at Times Beach and Love Canal. Data from sampling on the Parsons property indicated that dioxins were present in sediments of the unnamed tributary on plant property and in soil from an approximately 140-square-foot (13.01-m<sup>2</sup>) area underlying the former septic system leach field.

Acting under pressure from MDEQ, ETM removed the septic tank and leach field and properly disposed of the contaminated sludge and liquid that were present inside the tank. ETM, which did not use, store, or handle pesticides and solvents, connected its own process and sanitary wastewater piping to the Grand Ledge municipal sewer system. Eventually MDEQ issued a letter releasing ETM from any further liability for site cleanup. With no responsible party available to fund needed soil and groundwater remediation, the Parsons site was placed on the National Priorities List as a Superfund site in 1989.

In 1990, MDEQ and USEPA initiated the first remedial action to clean up site soil. More than 3,000 cubic yards (2,294 m<sup>3</sup>) of contaminated soil was remediated by using an innovative technology called in situ vitrification, or ISV. The basic concept behind ISV is melting the contaminated soil into a pile of fused silica. The contaminant is left in place, entombed forever in an unleachable block of glass. The Department of Energy developed this technology for use on some of its more recalcitrant contaminants such as radionuclides, polychlorinated biphenyls (PCBs), heavy metals, and mixed hazardous and radioactive wastes.

To start the vitrification process, an electric current is applied to an array of electrodes that have been driven directly into the contaminant mass. The electrodes are connected to large generators or directly to the regional power grid, and, as electricity passes between electrodes, the soil is heated to very high temperatures of 2,900–3,600°F (1,600–2,000°C). Between the time when the water in the soil's pore spaces boils off at 212°F (100°C) and begins to melt at about 2,612°F (1,100°C), the soil becomes non-conductive. Without an electrical current, there is no heating, and the soil starts to cool. In order to keep the electricity flowing and the soil heating, a layer of conducting material, usually a mixture of graphite,

fused silica, and salt, is spread out on the surface. This starter path remains conductive even as the pore water is driven off. After the melting point of the soil is reached, it again becomes conductive.

The melting point of soil depends largely on the alkali metal oxide (sodium and potassium) content. The more alkali metal oxide present, the higher the melting point. As the soil melts, the molten zone grows outward and downward as the probes descend through the liquefying material. When the desired depth is reached, the electricity is shut off and the electrodes disconnected. The end result is a dense, chemically stable, leach-resistant glass. Blocks of glass weighing as much as 1,400 tons (1,274 metric tons) at depths greater than 20 feet (6.1 m) have been made by using this process. Most of the void spaces in the soil are removed during melting, and volume reductions of 20–50 percent have been reported at some sites. During melting, organic compounds are vaporized and collected in a hood or tent for treatment prior to release into the atmosphere.

At the Parsons site, MDEQ and USEPA directed that the soil targeted for ISV treatment be excavated and placed, or staged, in a series of two concrete wall trenches 15 feet (4.6 m) deep and 27 feet (8.2 m) wide. One trench was 168 feet (51.2 m) long and the other 84 feet (25.6 m) long. Contaminated debris such as concrete, steel, used filters, and automobile tires was also included in these trenches. A two-foot (0.6-m) layer of uncontaminated soil was placed across the top of each trench. The trenches were divided into nine cells, each 27 feet long (8.2 m), by 27 feet (8.2 m) wide, by 15 feet (4.6 m) deep.

Vitrification of the contaminated soil at the Parsons site was scheduled to be completed in about three months but took almost a year. The reasons for this delay ranged from very stringent oversight by regulators that required permit modifications for almost every change in procedure to operational learning-curve issues on how best to manage the infiltrating groundwater and at what rate to supply power to the electrodes. Despite the extended schedule, overall, the remediation was successful. As the operators became more familiar with the system, they found that they could overlap the melt areas and needed only eight melts to treat the soil in the nine cells. Additionally, through proper system management, they could form a "cold cap," or thin surficial layer, of vitrified soil over the melt area and help contain vapors and fumes being given off during the process.

To evaluate the effectiveness of ISV, soil samples were taken before and after melting. These data indicated that ISV was very effective not only in reducing total contaminant concentrations, but also

in immobilizing the remaining contaminant mass into a nonleachable form.

Subsequent remedial actions included the excavation and off-site disposal of another 1,200 cubic yards (917.5 cubic m<sup>3</sup>) of contaminated soil that was identified during ISV. This volume of material was too low to justify reuse of ISV economically. Also, approximately 3,800 cubic yards (2,905 m<sup>3</sup>) of arsenic-contaminated soil was removed from areas across the highway from Parsons, washed there by surface water runoff from the site.

To address contaminated groundwater, MDEQ and USEPA took a much less aggressive approach. Water samples from approximately 70 private supply wells within a quarter-mile (0.4-km) radius of the site had been tested periodically and found not to be affected by site-related constituents, although some contained elevated levels of naturally occurring manganese and zinc. Wells in the area draw water from a deep bedrock aquifer that had not been contaminated by pesticides or other chemicals originating at the Parsons site.

On the basis of these findings and the fact that on-site, contaminated soil had been addressed, MDEQ and USEPA decided to implement a long-term monitoring program that includes periodic sampling of selected residential drinking water wells until 2018. If monitoring data indicate that contamination is moving toward private water supply wells, contingency plans have been established to provide these residents alternate drinking water supplies until they can be connected to the Grand Ledge municipal water supply.

*See also* ARSENIC; CHROMIUM; DIOXIN; INORGANIC POLLUTANTS; IN SITU GROUNDWATER REMEDIATION; MERCURY; ORGANIC POLLUTANTS; PESTICIDES; SOIL POLLUTION.

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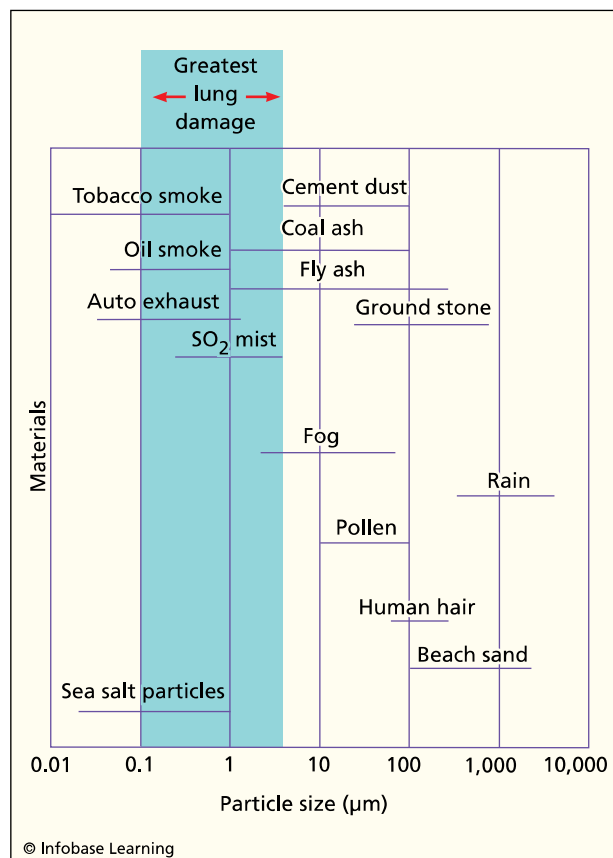
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**particulate** In the 1970 Clean Air Act, particulate was designated as one of the six "criteria" air pollutants along with carbon monoxide, lead, nitrogen oxides, sulfur dioxide, and volatile organic compounds. At that point, it was not subdivided and considered to be among the more benign of the six. With continuing research since, particulate has emerged as one of the most dangerous of the six, been officially subdivided into different types, and been subject to much more stringent regulations, which are controversial in that many scientists think that they are not stringent enough. It has been estimated to be responsible for as many as 65,000 deaths per year in the United States from respiratory effects and as many as 200,000 deaths per year in Europe under the old restrictions. This constitutes a 17 percent increase in mortality risk. In recent years, new legislation has been rushed into enactment to deal with this crisis. Even with the new legislation, people who have respiratory or cardiac problems who live in almost any urban area of the United States and even many suburban and rural areas must be extra careful about exposure to particulate pollution.

## PROPERTIES AND SOURCES

*Particulate* is a general term for any solids or small liquid particles that are suspended in air. They can be composed of literally hundreds of elements and compounds, some of which may be hazardous including heavy metals and asbestos. Particulate falls into several categories based upon size. Total particulate matter (TPM) is all suspended matter within the size range of 100 and 0.1 micrometers. Within this grouping, the PM<sub>10</sub> classification, are particles less than 10 micrometers, and PM<sub>2.5</sub> are less than 2.5 micrometers. The main reason for the subcategories are medical: PM<sub>10</sub>, or coarse, particles are respirable; PM<sub>2.5</sub>, or fine, particles can be absorbed directly into the bloodstream through the lungs. Primary particles, also known as direct particles, are emitted directly from their source as solids and are primarily PM<sub>10</sub> or larger. Secondary, or indirect, particles are formed in the atmosphere primarily through photochemical reactions of precursor





**Chart showing the sizes of particulate pollution and some common items for comparison in log scale. The sizes represented by the shaded area cause the greatest damage to human lungs when inhaled.**

chemicals and primarily fall into the  $\text{PM}_{2.5}$  range. Sources of particulates are both natural and anthropogenic. Natural particulate is a combination of solids including dirt, soil and rock dust, sea salt, pollens, molds, fungi, yeast, bacteria and viruses, ashes and volcanic ash, and liquid droplets of aerosols from biologic activities and volcanoes. Anthropogenic sources include cars, trucks, buses, construction sites, agricultural fields, unpaved roads, stone crushing operations, brickworks, cement works, quarrying, incineration, chemical factories, smoke-stack emissions from power plants and manufacturing plants, smelters, open burning, residential heating, and tobacco smoke. Much of the fine particulate forms from chemical reactions among sulfates from power plants, nitrates from motor vehicles, and industrial emissions and ammonia from feed lots. A recent study of fine particulate from Ontario, Canada, showed that the composition was 30–50 percent organic and elemental carbon from burning (soot), 30–40 percent sulfate from sulfur dioxide,

10–20 percent nitrates from nitrogen oxides, and 3–10 percent soil, but this varies widely with season and location.

### ENVIRONMENTAL RELEASE AND FATE

Particulate size fraction of 50–100 micrometers is heavy and tends to settle out close to the source or be washed out by precipitation. Coarse and fine particulate, by contrast, can be transported over great distances in suspension by wind before settling to the surface. This process can result in acidic lakes and streams and alter the nutrient balance in coastal waters, lakes, and large river basins depending upon the composition of the particulate. It can deplete nutrients in soils and damage sensitive forests and agricultural crops. It can also destroy the balance in ecological systems. Fine particulate can cause reduced visibility and haze in urban, suburban, and rural areas.

### HUMAN EXPOSURE AND HEALTH EFFECTS

More than 99 percent of inhaled particulate matter is directly exhaled or trapped in the upper respiratory tract and then exhaled. Of that which is not expelled, coarse particulate can lodge in the lung tissues and slow the exchange of oxygen and carbon dioxide in the blood, causing shortness of breath. This condition is exacerbated by irritation and swelling of airways and can lead to life-threatening situations. Lack of oxygen strains the heart. Fine particulate can be absorbed directly into the bloodstream through the lungs. This process is even more damaging to the cardiovascular system. This condition is especially dangerous to people who have cardiac or respiratory disease such as emphysema, bronchitis, chronic obstructive pulmonary disease (COPD), and asthma. Some studies suggest that children and elderly adults are also more sensitive to particulate. Short-term exposure to particulate can cause coughing, wheezing, respiratory irritation, and painful and labored breathing. Depending upon the composition of the particulate, symptoms may be even worse. Long-term chronic exposure to particulate increases the risk of lung diseases such as emphysema, bronchiectasis, pulmonary fibrosis, cystic lungs, and lung cancer. It induces the progression of atherosclerosis, affects heart rate variability and blood lipids, and increases the likelihood of blood clots and stroke. It also damages the immune system in the lungs and, in general, contributes to premature death. It has been estimated that chronic exposure to particulate shortens a person's life span by as

much as two years. Exposure of pregnant women to high levels of particulate has been linked to preterm deliveries, low birth weight, and possible fetal and infant deaths.

### REGULATIONS ON HUMAN EXPOSURE

The first U.S. Environmental Protection Agency (EPA) restrictions for particulate matter were imposed in 1970, but they did not discriminate among the types. In 1987, the regulations were revised to discriminate between total particulate matter (TPM) from that of 10 micrometers or less ( $PM_{10}$ ) to address emerging research on health issues resulting from exposure to this finer fraction. In 1997, the regulations were further revised to separate even finer particulate of 2.5 micrometers or less ( $PM_{2.5}$ ), which caused additional health problems. The 1997 regulations limited coarse particulate ( $PM_{10}$ ) to an annual arithmetic mean of 50 micrograms per cubic meter of air and a 24-hour maximum of 150 micrograms per cubic meter, not to be exceeded more than once per year. Fine particulate ( $PM_{2.5}$ ) was not to exceed 15 micrograms per cubic meter of air on an annual basis averaged over three years and 65 micrograms per cubic meter for the 24-hour maximum. This standard could only be attained if the three-year average of the 98th percentile of 24-hour levels did not exceed the limit. In 2006, these standards were further revised to revoke the limits for the  $PM_{10}$  annual levels and to reduce the 24-hour  $PM_{2.5}$  maximal level to 35 micrograms per cubic meter of air. In 2005, the EPA designated nonattainment areas for  $PM_{2.5}$  standards. There are 39 nonattainment areas, which constitute 208 counties or parts of counties. The majority are east of the Mississippi River in the middle latitudes of the country (including nearly the entire state of New Jersey) and a large swath of California. By 2008, the states with nonattainment areas were required to submit plans to correct these problems, and by 2010, they were required to have implemented them, although extensions and exceptions were possible.

These National Ambient Air Quality Standards reduced the six criteria air pollutants by 54 percent between 1970 and 2004. There are several EPA programs that have helped this reduction, including the Clean Air Interstate Rule for power plants in the eastern United States; the Clean Diesel Program, which will reduce diesel particulate by 90 percent; and the Clean Air Visibility Rule, which reduces emissions that affect national parks. Coarse particulate was reduced by 25 percent between 1990 and 2005, although it has remained flat since 2003.

Fine particulate was reduced 7 percent between 1999 and 2005. Some scientists argue that the new standards are not stringent enough and may still allow as many as 20,000 deaths per year in the United States and leave 165 million Americans in areas with dangerous particulate levels. Direct intervention from the White House is blamed for the lax standards. The European Commission has instituted a two-phase reduction in particulate. Between 2005 and 2010, the yearly average could exceed 40 micrograms per liter of air, with a daily maximum of 50 micrograms not to be exceeded more than 35 days per year. After 2010, the maximal yearly average will be 20 micrograms per liter, with a daily maximum of 50 not to be exceeded more than seven days per year.

See also AIR POLLUTION; PARTICULATE AIR CONTROL DEVICES; PRIMARY AIR POLLUTANTS.

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**particulate air control devices** There are a number of technologies that can be used to mitigate the effects of particulate releases from the burning of fossil fuels or during manufacturing processes. Modern boilers and manufacturing systems are designed to minimize the release of contaminants into the air. Many are computer operated and automatically adjust temperatures, feed rates, and oxygen/fuel ratios to maximize combustion efficiency. No system is 100 percent efficient, and to remove the particulate that is generated, physical separation and collection devices are needed. There are six basic types of particulate control devices.

### SETTLING CHAMBERS

Settling chambers are closed vessels where the waste gases are diverted to slow them and allow particulate to settle into a bin, or hopper, for collection and later recycling or disposal. This type of device relies on gravity to remove the particulate. They are typically used for larger particulate, that with a diameter of 10–50  $\mu\text{m}$ , because finer particulate would take too long to settle and require impracticably large chambers.

Settling chambers, also called gravity collectors, expansion chambers, or outfall collectors, are usually configured as long horizontal rectangular boxes with an inlet at one end and a discharge point (vent or stack) at the other. Inside the chamber are drag scrapers, or screw conveyors, that help collect and remove the settled particles. Although they have a low collection efficiency (less than 10 percent) for small particulate, settling chambers were a popular early method of air pollution control. They were inexpensive, reliable, and simple to operate.

Metal refining facilities used settling chambers to collect arsenic-laden particulate generated from the smelting of certain types of copper ores. Unburned carbon particulate or soot from coal-fired electrical generating stations and large commercial boilers was collected in settling chambers for reinjection into the furnaces. Today, the use of more efficient combustion technologies and the more stringent air pollution requirements of the 1960s and 1970s have made the use of settling chambers as a primary air pollution control device rare. Not many remain in commercial operation, and most are relegated to the status of “precleaners,” removing large particulate prior to the routing of the waste gas to another treatment device.

### CYCLONES

Cyclones are devices that force particulate entrained in a waste gas into a special cone-shaped cylinder. Cyclones can be designed with one large chamber or consist of a series of smaller, interconnected tubes or partitions. Regardless of the design, the basic operating principal requires the gaseous waste stream to be blown downward as it enters the cyclone. Centrifugal force pushes the particulate in the waste stream onto the walls of the cylinder, where it falls to the bottom for eventual collection and disposal. The now-treated gas then is discharged out of the cyclone. Cyclones are inexpensive, easy to install and operate, and fairly maintenance-free. Particulate is collected in dry form so that it can be reused in the manufacturing process, recycled, or disposed of at an approved facility.

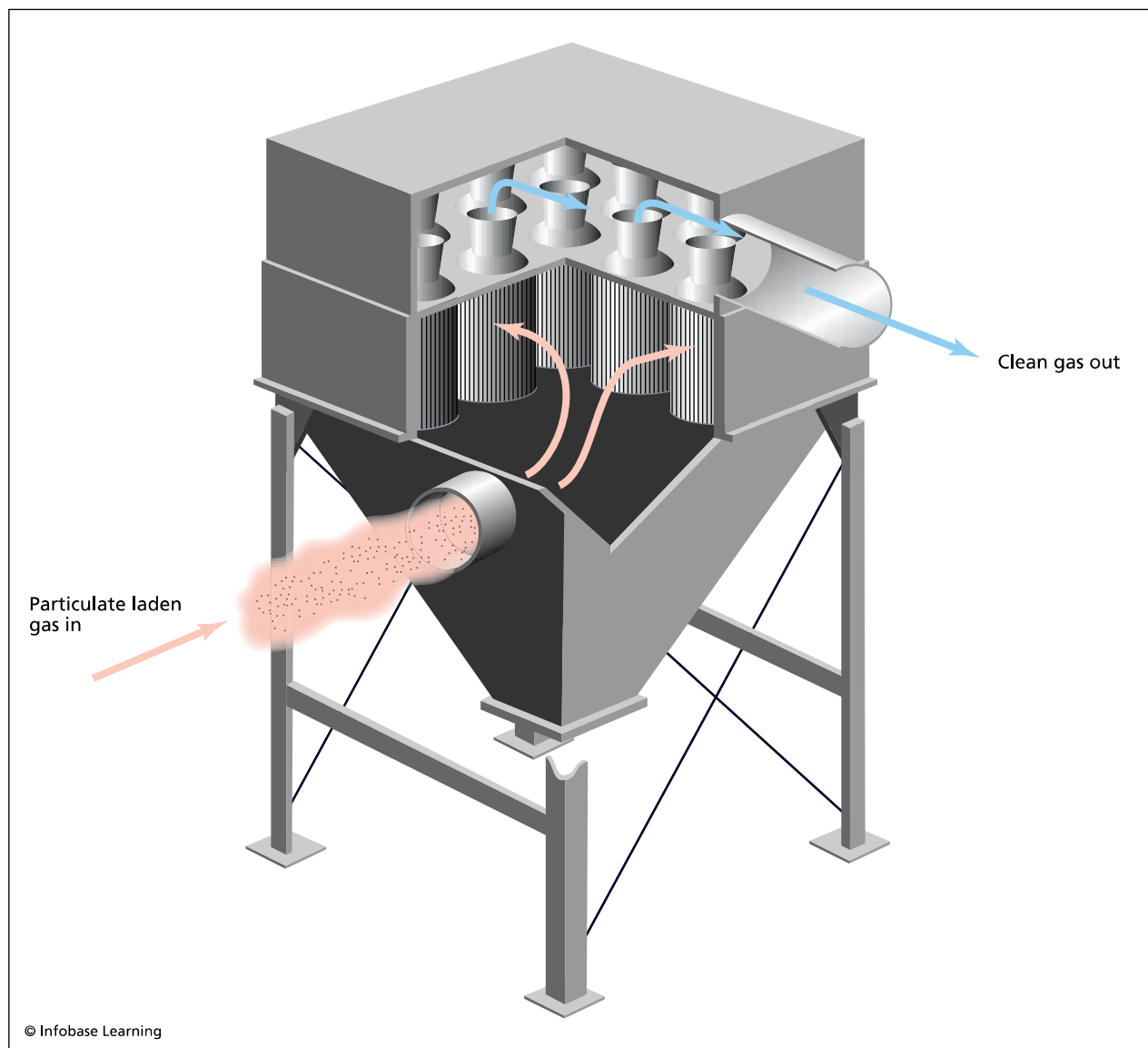
A good example of how cyclones are used to control air emissions is at Wolverine Bronze, a metal foundry in Roseville, Michigan, about 20 miles (32 km) north of Detroit. In order to cast liquid metal into various shapes, a pattern is created by using material called foundry sand. Made up of clean, uniformly sized high-quality silica sand that is bonded usually with clay or a special chemical, foundry sand is used to form molds for ferrous, aluminum, bronze, and other types of metal castings. The iron and steel industries use about 95 percent of the foundry sand produced in the United States for making automotive parts, structural beams, and machine parts. The sand is expensive, and over time it becomes contaminated with binding agent as well as bits and pieces of the metals that are poured into it.

Most foundries recycle the sand by pouring it into a shaker that breaks up the sand lumps and sieves out the metal particles. The sand is then heated to burn off residual casting binder. As the sand is handled, dust is given off and can create both a worker and environmental hazard. At Wolverine Bronze, the foundry sand recycling system generates about four tons (3.6 metric tons) of sand per hour and typically operates as long as 13 hours per day, generally at night and weekends, when electrical rates are low. Dust from the recycling system is collected and managed by a three-stage system. A sieve is used to screen out the larger particles, with the exhaust fumes sent to a cyclone for separation of finer material. Finally, the remaining fines are passed through a baghouse before the carrier air is discharged. Wolverine Bronze has operated this system for more than 10 years with no violations of its air permit limitations.

Cyclones work best on particulate larger than 10 micrometers; smaller size particulate (PM<sub>2.5</sub>) tends to remain in waste gases. High-efficiency cyclones that are available can collect particulate as large as 5 micrometers, but these are more expensive and difficult to operate and maintain. For these reasons, cyclones generally are used as pretreatment or pre-cleaning devices, removing larger particulate and conditioning the waste gas for treatment by more aggressive processes. Air emissions from mineral and chemical industry processes involving crushing, grinding, and calcining (heating) often are pretreated with cyclones. Emissions from fossil fuel-fired boilers or furnaces typically are discharged to a series of cyclones prior to treatment by fabrication filtration, scrubbing, or electrostatic precipitation.

### FABRIC FILTRATION (BAGHOUSES)

Fabric filters are essentially giant vacuum cleaner bags. The waste gas is forced through a series of



**Cutaway diagram illustrating a vertically mounted cartridge baghouse. Contaminated air enters the port on the left side and is driven through the vertical filter cartridges and the manifold before exhausting through the port on the front. Particulate can drop into the hopper beneath for collection.**

cloth filters (bags or cartridges) that physically separate the particulate from the gas stream. Filters are most commonly made of fabric but can be any coarse, granular substance that effectively traps particulate. Materials used include cotton, wool, nylon, and polypropylene; Teflon®, Nomex®, and fiberglass have also been fabricated into filters for use in specialty high-temperature or corrosion applications. Filters are wrapped around hollow tubes and arranged in rows to provide a large surface area through which the waste gas passes. The filters, tubing, and associated blowers and vents are big and noisy, and they are usually placed in separate, stand-alone structures, called baghouses.

Capture efficiencies of more than 95 percent for 0.5- $\mu\text{m}$  particulate are achievable. After the solids are removed, the cleaned gas is discharged into the atmosphere. Particulate is removed from the filters by shaking them or by back-flushing, which involves reversing the flow of air and blowing it through the filters from the other direction. The particulate is collected in a hopper or drum and is either disposed of or recycled.

Although there are many industries that generate particulate during their operation, the processing and production of taconite present a particulate challenge to the effective management and control of dust and fines. Taconite is a variety of chert, a light-



colored silica mineral mixed with magnetite and hematite, both of which contain iron. Almost all the iron ore remaining in the United States is taconite, and most is from the Upper Peninsula of Michigan. To extract the iron, the taconite is crushed and ground into small particles. The iron is then recovered by using magnets or gravity separation because the iron minerals (magnetic and hematite) are much heavier than the silica mineral (chert). Enormous quantities of particulate are produced by these crushing and grinding operations, and particulate must be prevented from entering the atmosphere, where it can adversely affect local air quality, compromise the health of mill employees, and damage expensive processing equipment.

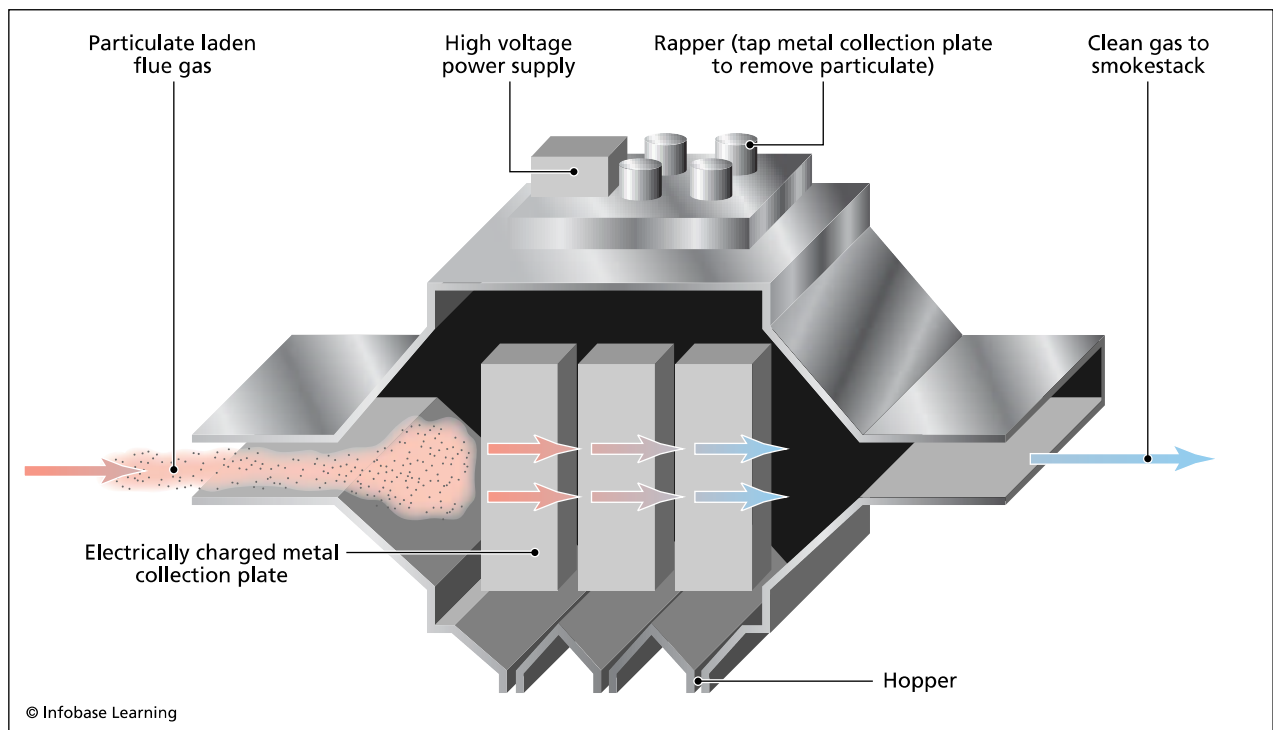
At the taconite mine and mill in Babbitt, Minnesota, 200 miles (322 km) north of Saint Paul, engineers installed a fabric filtration system to control dust at the truck dump pit, where the processed ore is loaded for shipment, and at the primary crusher, the largest in North America. Once installed, the system was successful in reducing dust in the loading area by 50 percent, and air emissions were substantially below U.S. Environmental Protection Agency (EPA) regulatory limits.

Baghouses are expensive to build and maintain, and fabric filtration is not effective in humid environments. They commonly are used with waste gas

streams that tend to be dry such as at cement plants, steel mills, and quarry processing. Fabrics can be damaged if waste gas temperatures are too high or if the air emissions to be treated contain combustion or processing by-products that are acidic. In high-volume settings, fabric filtration is at a disadvantage when compared with other air pollution control technologies because of the large pressure drop that occurs when the waste gas is forced through the filters. This pressure drop slows gas discharge rates; increases energy demand because the motors, blowers, and other equipment have to work harder; and can cause premature wear or damage.

### SCRUBBERS

Scrubbers use a liquid, usually water, to remove particulate from a waste gas. Water is sprayed into the waste gas as it flows up the exhaust stack or process vent. The water droplets surround and trap the particulate, washing it down into a collection device for later treatment. Some scrubbers are designed to increase the size of the particulate, by combining it with a water droplet. This droplet is then removed in another waste gas treatment step. The ability of a scrubber to remove particulate decreases as the particle size decreases. More water is needed to remove smaller particles from the waste gas. Scrubbers are



**Cutaway diagram of an electrostatic particulate removal system. Particulate adheres to charged metal collection plates as it passes through and drops into hoppers below.**

often used in combination with cyclones, with water jetted into the cyclone to help capture and wash down the particulate.

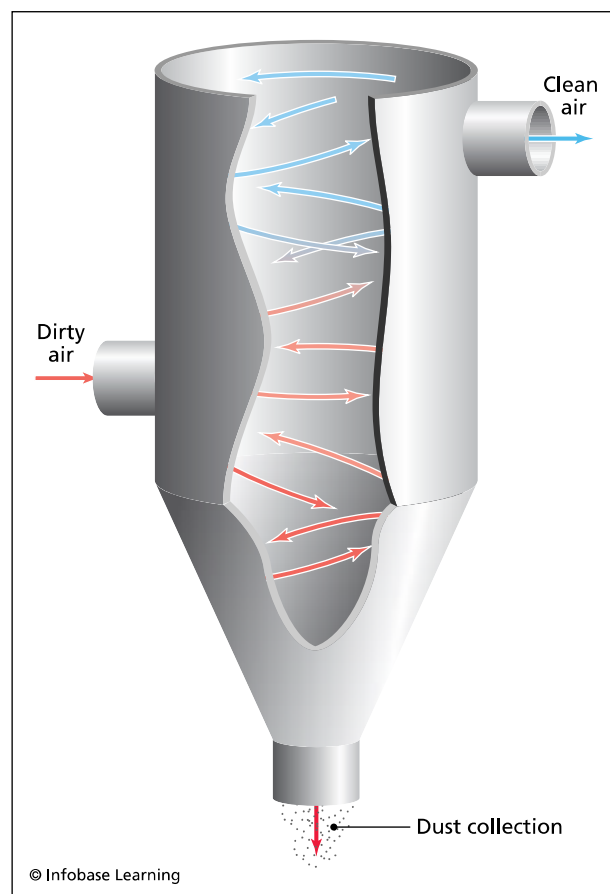
Depending on their design, scrubbers can treat flammable or explosive dusts, cool waste gases prior to discharge, and neutralize acidic mists and vapors. At the top of the stack, or discharge vent, demisting devices are installed to prevent very fine droplets of water (aerosols) created during the scrubbing process from being carried out with the exhaust gas.

For one company in Ohio, the installation of a scrubber to treat emissions from its industrial furnace solved two problems. Teflon-coated baking trays are refurbished at the plant by first baking off the nonstick coating at high temperatures in a furnace. This produces particulate in the 5- $\mu\text{m}$  range as well as hydrofluoric acid, a very corrosive substance. To remove the fine dust and soot from this process waste gas stream, the company installed a scrubber. In addition to a particulate removal efficiency of 99 percent or better, a strong base (sodium hydroxide) was mixed with the scrubber solution. The solution, which was continuously recycled during off-gas treatment, was successful in neutralizing the acid and significantly reduced equipment corrosion.

Large amounts of clean water are needed to operate scrubbers, and the waste liquid and/or resulting sludge needs to be treated and disposed. Capital and operating costs associated with the installation and use of wet scrubbers are high, and most industries tend to use scrubbers only when other waste gas treatment technologies cannot meet required treatment levels. Scrubbers are used to control particulate releases from utility, industrial, and institutional boilers fueled by coal, oil, wood, and even used oil. They also manage emissions from the chemical, mineral products, pulp and paper, and other manufacturing industries, as well as municipal solid waste (trash) incinerators.

### ELECTROSTATIC PRECIPITATORS (ESPs)

ESPs are among the most effective means of removing particulate from a waste gas. Operating on the simple principle that positively and negatively charged particles are attracted to each other, ESPs are large electrically charged metal plates that line the smokestack or exhaust vent. As the waste gas enters the stack, it passes through negatively charged wires or rods and is ionized. It then flows past a positively charged collection plate, where the particulate is removed from the waste gas without affecting its flow-through velocity. The collection plates are cleaned periodically of accumulated particulate



**Cutaway diagram of a cyclone particulate control device in which particulate is liberated from contaminated air by centrifugal force as it spins around the metal tank**

by automatically operated rappers, small mallets or hammers that gently bang on the collection plates, loosening the particulate and letting it fall into a hopper for collection and recycling or disposal.

ESPs work well in high-volume gas settings (up to 4 million cubic feet per minute [113,267 m<sup>3</sup> per minute]) and can collect submicron (<1  $\mu\text{m}$ ) size particulate. They are very energy efficient and are not bothered by relatively high temperature gases (as high as 1,200°F [649°C]). Collection efficiency typically ranges from 98 to 99 percent. One disadvantage of ESPs is that they are large. The waste gas moves through the system at velocities in the range of meters per second, but the particulate is attracted to the collection plate at velocities only in the range of meters per minute. This means that the collection chambers have to be big and are sized on the basis of anticipated discharge velocities. Despite this drawback and the fact that ESPs are expensive to design and install, they are widely used in industrial applications, especially in coal-fired power plants.

Newport Towers is an upscale commercial building on Jersey City, New Jersey's, "gold coast" waterfront and has spectacular views of the Manhattan skyline. One of the many amenities the building features is a large cafeteria for tenants and guests. Smoke generated by cooking produces particulate between 0.3 and 0.8  $\mu\text{m}$ . To maintain the fashionable look of the building and to be a good neighbor, Newport Towers installed a heavy-duty, three-pass electrostatic precipitator (ESP) system. In this system, emissions from kitchen stoves and ovens pass through three ESPs, each controlled by a microprocessor that makes automatic adjustments in electrical charging and, therefore, very high particulate capture rates, resulting in no visible emissions from the building. The ESP system was easy to install, and maintenance (cleaning) is needed only once a year.

Desirable characteristics such as these account for the wide use of electrostatic precipitators by industry, especially in the electrical power-generating field. In addition, the energy expended in separating particulate from a waste gas stream by means of an electrostatic precipitator acts solely on the particulate, and not on the gas stream. This is unique for collection equipment in the air pollution field, since other devices based on different principles of separation require that energy be expended on the entire gas stream in order to achieve the desired effect.

See also AIR POLLUTION; PARTICULATE.

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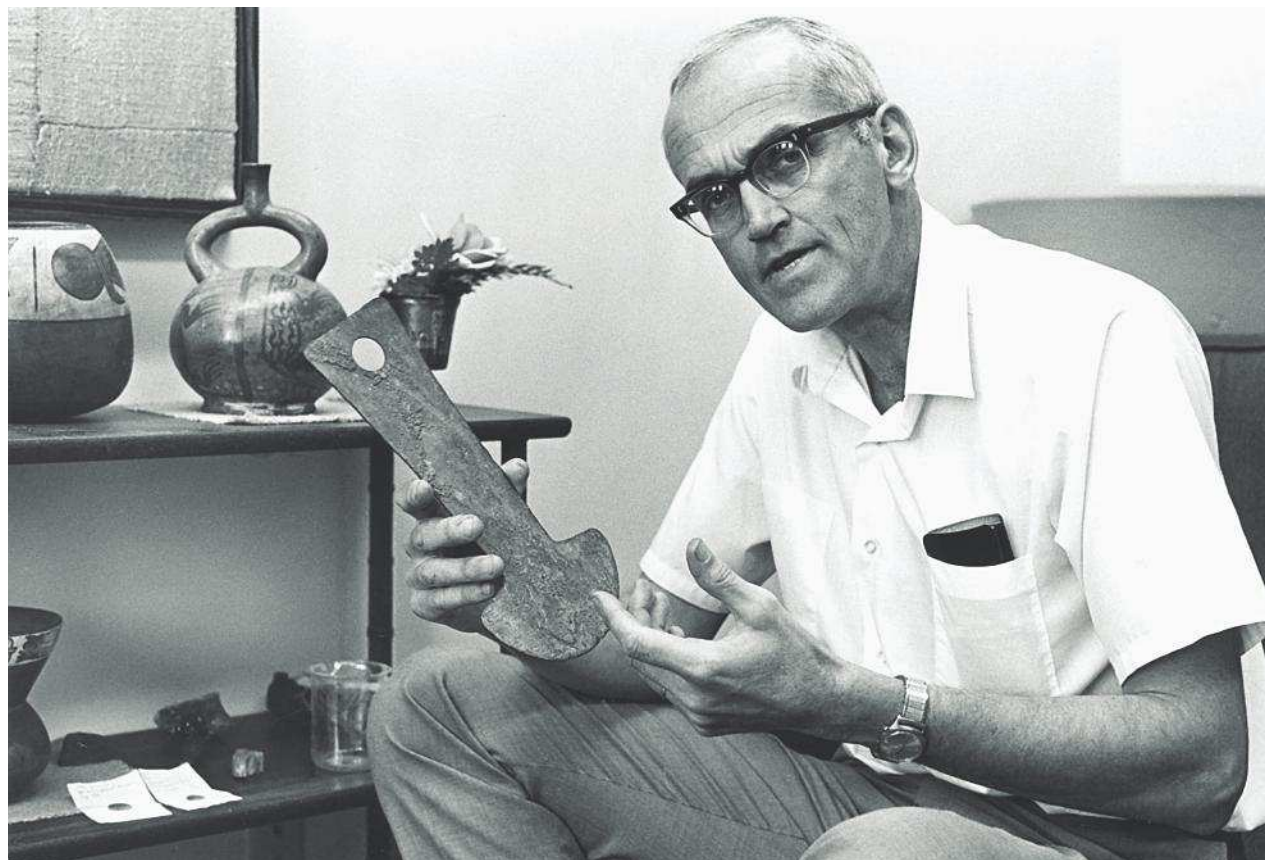
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**Patterson, Clair Cameron "Pat" (1922–1995)** *American Chemist, Geologist* Clair Cameron "Pat" Patterson made an amazing contribution to the environment and public health: He almost single-handedly eliminated all commercial uses of lead. What is even more amazing is that he had no training as a politician or advocate; he was a soft-spoken man of simple means and an excellent scientist. In many of the political issues that involve science, warnings from scientific data are used by advocates mainly as conveniences to prove a point in some larger struggle. In other cases, they are only used if there is no other choice. In this case, against all odds and personal and professional attacks, Patterson stood his ground that lead was overused and dangerous, citing his own meticulous scientific studies, and, in the end, he prevailed.

#### BIOGRAPHICAL INFORMATION

Pat Patterson was born on June 2, 1922, in the small town of Mitchellsville, Iowa, near Des Moines. He attended a small rural high school with fewer than 100 students and graduated in 1940. He earned a bachelor of arts degree in physical chemistry from Grinnell College, Iowa, in 1943. It was there that he met and married his wife, Lorna McCleary. Patterson earned a master's degree in 1944 from the University of Iowa in chemistry, specializing in molecular spectroscopy. His thesis adviser, George Glockler, invited him to the University of Chicago to work on the Manhattan Project to help develop the atomic bomb. After several months, Patterson decided to enlist but was rejected because of his high security clearance. Instead, he was transferred to Oak Ridge, Tennessee, to continue work on the Manhattan Project. It was there that he became familiar with mass spectrometry of uranium isotopes. By accelerating uranium atoms along a magnetized flight tube, masses of the various isotopes can be determined. Isotopes of an element have the same number of protons and electrons and, therefore, the same name but varying numbers of neutrons; thus, the atomic mass varies. About 25 percent of isotopes of elements are radioactive. Uranium has several radioactive isotopes.

After the war, Patterson returned to the University of Chicago to earn a Ph.D. As a result of his experience with mass spectrometers, Harrison Brown, his adviser, assigned Patterson a dissertation on lead isotopes in 1948. He developed the first isotopic methods to determine the age of rocks for his dissertation in 1951 by using a mass spectrometer. To accomplish this, he had to devise laboratory procedures and in



Clair C. Patterson, 1972 (Archives, California Institute of Technology)

the process found that background levels of lead were much higher than he had expected. He had to develop procedures to keep the lab ultraclean or the samples for study would immediately become contaminated by ambient lead.

Patterson remained at the University of Chicago as a postdoctoral fellow under Brown, but then followed him to the California Institute of Technology the next year. Patterson turned his attention to lead isotopes in meteorites and, in 1953, determined that all meteorites have the same age. This discovery was a breakthrough because it meant that meteorites all formed at the same time. The only event that could link all of these objects from such distant parts of the solar system was the formation of the solar system. Patterson was able to report that the age of the Earth and solar system was 4.55 billion years as a result of this work. This discovery was hailed as one of the greatest in the 20th century by the scientific community. Even more impressive is that with all of the additional research and better orders-of-magnitude technology, this age still stands today.

For any other scientist, such a momentous discovery would have been more than enough for a

whole career. Patterson, however, who was now a faculty member at Cal Tech, was not satisfied. He began characterizing common geological materials in terms of their lead contents and isotopes. It would be this work that would lead to his concern about anthropogenic lead.

### BATTLE AGAINST ANTHROPOGENIC LEAD

As the result of his great efforts to build a "clean lab," where he could analyze small quantities of lead, and his characterization of lead contents of normal geological materials, Pat Patterson realized that there was an inordinate amount of lead in the modern environment. By 1962, Patterson and his colleague Tsaihwa Chow showed that anthropogenic lead was being deposited at the astounding rate of 80 times that in the oceans. In 1963, he showed that surface water contained three to 10 times as much lead as deep ocean water, whereas, as with other heavy elements, it should have been much less. The first direct strike at industry occurred in 1965, when he published a meticulous study titled "Contaminated and Natural Environments of Man." It showed that, in



contrast to the common conception that industry increased exposure to lead no more than twofold, Americans were being exposed to lead at 100 times natural levels (within one-half the level of outright lead poisoning.) These levels were found within the blood of the volunteers. He identified gasoline (leaded), paint, solder in pipes and electrical devices, and pesticides as the main industrial sources. With Patterson's reputation as an eminent scientist, these findings were taken seriously by the scientific community, although there was some skepticism.

As a result, Patterson was attacked both personally and professionally as a zealot and a rabble-rouser rather than a scientist by respected industry professionals. The attacks did not dissuade him. Instead, he wrote to Governor Pat Brown of California on October 27, 1965, warning him about lead in the air, especially in the Los Angeles area. This first attempt was politely rejected. He had also sent a similar letter to Senator Edwin Muskie, the chairman of the Subcommittee on Air and Water Pollution, on October 7, 1965. As a result of this letter, Patterson was invited to testify at a hearing in Washington, D.C., on June 15, 1966. Perhaps encouraged by the success on the national front, Patterson sent a second letter to Governor Brown on March 24, 1966, which was better received. On July 6, 1966, the California Department of Public Health was ordered to establish air quality standards by February 1, 1967.

All the success in advocacy could have dissuaded Patterson from his research, but instead, he increased his efforts to collect data to support his convictions. In 1970, he released a paper in which he studied lead in ice cores from both Greenland and Antarctica. He found that lead level in snow from Greenland was 100 times as great at that time as it had been in preindustrial times. The Antarctic data showed a 10-fold increase largely because there is less land, fewer people, and less industry near the Southern Pole. Despite these findings, the National Research Council released a subsequent report on airborne lead that largely ignored Patterson's work. Again, this did not stop him, and in 1973 he showed that lead from the burning of gasoline was permeating even the most remote wilderness areas. Whether it was this study, the whole barrage of Patterson's work, or the growing public support, the EPA announced in December 1973 that there would be phased reduction of lead in gasoline of 60–65 percent. Patterson's findings were finally being recognized, and success did not slow his efforts. He continued to collect data, showing in 1975 that high concentrations of lead could overwhelm a plant's natural defenses that would exclude it from their tissues. Perhaps the most

interesting of his studies was the 1979 comparison of 1,600-year-old Peruvian skeletons with modern human bones that showed an increase in lead level of 700–1,200 times in modern humans. Patterson's next target was the removal of lead from food. In 1979, he informed the EPA that their methods were not sensitive enough to test properly for lead in tuna. On October 10, 1981, Patterson participated in a symposium on this issue in Washington, D.C., which was attended by the EPA and Bureau of Foods. Within a few months, the EPA was meeting Patterson's standards. In 1980, Patterson participated in a study that showed excessive levels of lead in canned goods from the solder used in sealing the lids. By 1991, all lead had been removed from cans, as well as paints, water lines, and gasoline, among other materials, and the lead content of new-fallen snow in Greenland had decreased by a factor of 7.5 relative to that of 1971. Patterson almost single-handedly had greatly enhanced public health.

### RECOGNITION AND AWARDS

Pat Patterson's achievements were not unnoticed by the scientific community and the world. He was a member of the National Academy of Sciences and was awarded their J. Lawrence Smith Medal in 1973. He was also the 1995 Tyler Prize laureate for environmental achievement, among many other honors. Perhaps the most impressive recognition was the naming of asteroid 2511 after him as well as a mountain peak in the Queen Maude Mountains of Australia. He even served as the model for the character Sam Beech in the Saul Bellow novel *The Dean's December*. Very few scientists, no matter how great their achievements, have received such honors.

### IMPACT ON SOCIETY

It is rare for one person to have such an impact on an environmental issue. Other environmental pioneers such as Rachel Carson and Roger Randall Daughan Revelle identified a problem and called it to public attention. Pat Patterson is unique in that he identified a major problem and saw it completely through to resolution. Gasoline, paint, and pipe solder are now all lead-free as a result of the work of Pat Patterson, which is also the reason children are now tested for lead poisoning.

Pat Patterson retired from the California Institute of Technology in 1987 but remained active in both his research and activism. He died of asthma on December 5, 1995, at his home in California.

See also ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; LEAD; RADIATION.

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**PCBs (polychlorinated biphenyls)** According to the U.S. Environmental Protection Agency (EPA), PCBs are among the most widely studied environmental contaminants. In 1976, in large part as the result of the persistence and toxicity of PCBs in the environment, the U.S. Congress enacted the Toxic Substances Control Act, which specifically prohibited the manufacture, processing, and distribution of PCBs. The reasons for all of the concern are the documented and widespread adverse health effects. They are known carcinogens for animals and strongly suspected to be carcinogens for humans. They also have been shown to have strongly adverse effects on the immune system, the reproductive system, the nervous system, and the endocrine system in animals and humans. Their chemical stability and persistence in the environment make them especially dangerous.

PCBs occur in significant quantities in at least 500 of the first 1,598 hazardous waste sites (Superfund sites) on the EPA National Priorities List (NPL), making them an important contaminant of concern in the United States. As a result of their widespread distribution and adverse health effects, PCBs are ranked as the fifth worst environmental pollutant of the 275 listed on the 2007 CERCLA Priority List of hazardous substances.

One of the most famous cases involving PCBs is the dumping of between 209,000 and 1.3 million pounds (94,800 and 590,000 kg) of PCBs into the Hudson River of New York by the General Electric Company. The PCBs originated at two capacitor factories at Hudson Falls and Fort Edward, New York, and turned 200 miles (120 km) of this important

river into a designated Superfund site. As a result, fishing was banned in the Upper Hudson from 1976 to 1995, but it was renewed on a catch and release basis. General Electric argued that dredging the river would release more PCB into the environment than leaving it sequestered in the sediments. The EPA did not agree, and the final resolution was in late 2006, when it was agreed that dredging would begin in 2008.

## PROPERTIES, USES, AND PRODUCTION

Polychlorinated biphenyls are a group of mixtures of manufactured organic chemicals that form 209 individual compounds, called congeners. They range from viscous oily liquids to waxy solids that are colorless to light yellow, although some can exist as vapor in air. PCBs have no taste or smell, and they are soluble in most organic solvents, oils, and fats. They were regarded as miracle substances when they were invented, in the late 1920s, because of their inflammability, chemical stability, high boiling point, and electrical insulating properties. The main use of PCBs was as a cooling and insulating fluid for industrial transformers, capacitors, and other electrical equipment. They were produced by Monsanto from 1930 to 1977 under the trade name Aroclor and by General Electric as Pyranol. Other names include Chlorinated diphenyl, Clophen, Kanechlor, Fenclor, Chlorextol, Dykanol, Inerteen, Monter, Pyralene, Santotherm, Sovol, Therminol, and Noflamol. They were used in hundreds of industrial applications including electrical, heat transfer, and hydraulic equipment; household appliances; plastic and rubber products; plasticizers in paints, pigments, and dyes; microscope and other oils; adhesives and sealants; and copy paper. By the time production of PCB ended in 1977, more than 1.5 billion pounds (682 million kg) had been manufactured in the United States alone. It is literally everywhere and will take decades to eradicate completely from regular use, much less from the environment.

## ENVIRONMENTAL RELEASE AND FATE

PCBs entered the natural environment during their manufacture through air, water, and soil from accidental spills and leaks. They have continued to enter the environment through leaks in operational devices that contain PCBs and disposal methods, either illegal or from leaky older hazardous waste sites. Incineration of PCB products under improper conditions may also release it into the environment. Once PCBs are in the natural environment, they are very difficult to remove. They are chemically

stable, so they persist for a long time and may be transported long distances from a spill site without alteration. Although PCBs may remain dissolved in water for long periods, they have a tendency to bind strongly to organic compounds in soils and bottom sediments. Their chemical stability also allows them to bioaccumulate in aquatic organisms. By the time PCBs reach the top of the food chain, they may be thousands of times more concentrated in the fish and marine mammals than they are in the surrounding water. People who eat fish that inhabit PCB-tainted waters are at great risk for poisoning.

Disposal of PCBs can be done by physical, microbial, and chemical processes. PCBs have been placed into landfills in large quantities, primarily in the form of transformers and capacitors. Incineration of PCB-bearing waste is another form of disposal, but they must be burned at temperatures of 2,192°F (1,200°C) or more for at least two seconds in the presence of fuel oil and an excess of oxygen. Improper incineration of PCBs can result in the formation of other dangerous compounds such as dioxins in addition to remnant PCBs. Ultrasound can also be used to destroy some PCB congeners if they are water soluble and have low chlorine content. Gamma irradiation can destroy PCBs in the presence of mineral oil or isopropanol. These destructive physical methods tend to be complex and relatively expensive. Microbial methods are also not without complications and expense. Bacteria tend to be selective as to which compounds they will dechlorinate, and even when they are effective, they tend to be very slow. Although bacteria may be effective in dechlorinating PCBs in laboratory conditions, they are typically much less effective in natural settings. The numerous chemical methods for PCB destruction are also only partly effective and only under specific conditions. They are typically quite costly. In many cases, the affected soil, dredge sediments, or water is simply removed and stored.

### TOXICITY AND HEALTH EFFECTS

Long-term exposures of rats to PCBs have resulted in a significant increase in liver cancer. Studies of workers exposed to PCBs similarly found increases in rare liver cancers, as well as malignant melanoma, but several others were inconclusive. It is suspected that other factors such as smoking and alcohol consumption may exacerbate the effects. Studies on monkeys and other animals found significant effects of PCBs on the immune system including a decrease in size of the thymus gland, reduction in response of the immune system to standard stress tests, decreased resistance to Epstein-

Barr virus, and increase in viral infections including pneumonia. Humans have a similar response to PCB exposure including increased risk of Epstein-Barr virus and non-Hodgkin's lymphoma. The effects of PCBs on reproductive systems of monkeys and other animals include low birth weight, conception rates, and live birth rate, as well as low sperm counts among rats. Fish apparently have the same problems. These effects are long term even long after exposure has ended. Babies of women exposed to PCBs during factory work showed similar low birth weight and significant decrease in gestational age. When newborn monkeys are exposed to PCBs, they show significant long-term decrease in neurological development including learning, short-term memory, and visual recognition. Human babies show similar learning deficits, problems with motor skills, and neurobehavioral problems. The endocrine disruption from PCB exposure includes decreased thyroid hormone levels, reducing normal growth and development, as well as hearing loss in animals and probable similar effects on humans. Other effects on humans and animals include acne-like skin conditions, anemia, and ocular effects; elevations in blood pressure and serum triglyceride and serum cholesterol levels; and various degrees of liver and stomach toxicity in rodents and other animals. PCBs tend to be concentrated in human breast milk, providing an even more dire threat to children.

### REGULATIONS ON HUMAN EXPOSURE

As a result of these significant adverse health effects, many federal agencies have imposed limits on human and environmental exposure to PCBs. The EPA limits PCBs in drinking water to less than 0.5 part of PCBs per billion parts (ppb) under the Safe Drinking Water Act. The EPA further regulates the level of PCBs in lakes and streams to no greater than 0.17 part of PCBs per trillion (ppt). By law, industrial releases of one pound (0.45 kg) or more of PCBs into the environment must be reported to the National Response Center. The U.S. Food and Drug Administration (FDA) limits the content of PCBs in food including 0.2 part per million (ppm) in infant and junior foods, 0.3 ppm in eggs, 1.5 ppm in milk and other dairy products, 2 ppm in fish and shellfish, and 3 ppm in poultry and red meat. Several states and local jurisdictions have their own regulations regarding PCBs, especially with regard to fish and wildlife consumption. The Occupational Safety and Health Administration (OSHA) limits exposure for workers to less than 1 mg per cubic meter of air (mg/m<sup>3</sup>) over a period of eight hours for five days

per week for 42 percent chlorine PCBs, or 0.5 mg/m<sup>3</sup> for 54 percent chlorine PCBs. The National Institute of Occupational Safety and Health (NIOSH) recommends that workers not breathe air higher than 1 microgram per cubic meter of air (mcg/m<sup>3</sup>) for 42 or 54 percent chlorine PCB levels over a 10-hour-workday, 40-hour workweek. In the 1981–83 NIOSH National Occupational Exposure Survey, only 13,871 workers were exposed to PCBs in the workplace, mainly because it had been banned from most applications by then.

See also HUDSON RIVER PCB POLLUTION; ORGANIC POLLUTANTS; POINT SOURCE AND NON-POINT SOURCE POLLUTION; SUPERFUND SITES.

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**PCE (tetrachloroethylene)** Also commonly known as perc, PCE gained fame from its portrayal in the popular movie *A Civil Action*, which centers around a lawsuit over a cluster of leukemia cases, ostensibly in Massachusetts. The reality is that PCE is one of the most widespread contaminants, affecting virtually everyone to some degree, and, as such, is a significant environmental concern. PCE is a synthesized compound that is classified as a halogenated aliphatic hydrocarbon, and it is used primarily as a solvent in many applications. It is also a hazardous chemical that is toxic to humans and a threat to the

environment. PCE is also known as Ethylene tetrachloride, Perchloroethylene, Ankilostin, Didakene, Fedal-un, Nema, Percdene, Persec, Tetlen, Tetracap, Tetraleno, Tetropil, Antisal 1, Dow-per, Perawin, Perchlor, Percosolv, Perklone, Tetraguer, Tetralex, and Tetravec. PCE has been identified in 771 of the first 1,430 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) in which it was tested. This is a very high percentage relative to other pollutants in such sites. The widespread nature, toxicity, and other physical characteristics led PCE to be rated as the 31st most hazardous pollutant on the 2007 CERCLA List of the top 275 pollutants.

### PROPERTIES, USES, AND PRODUCTION

PCE is a colorless, strong-smelling, volatile liquid, which is categorized as a dense nonaqueous-phase liquid (DNAPL). In the 1970s, PCE was used 58 percent for dry cleaning and textile manufacture, 18 percent for metal cleaning, 12 percent in chemical production, and 12 percent for miscellaneous uses. By the mid-1990s, usage had shifted to 55 percent for dry cleaning and textile manufacture, 11 percent for metal cleaning, 29 percent in chemical production, and 5 percent for miscellaneous uses. Through the 1990s, PCE use in dry cleaning decreased by 60 percent so that by 2000, 21 percent was used for dry cleaning, and 50 percent was used in chemical production. Chemical production is primarily as an intermediate in the manufacture of refrigerants and in production of alkalis and chlorine, among others. The miscellaneous uses include insulating fluid and cooling gas in transformers; as a component of paint removers, printing ink, adhesives, paper coatings, and leather; as an extractant in pharmaceuticals; and in aerosol applications such as water repellants, automotive cleaners, silicone lubricants, and spot removers.

PCE was first synthesized in 1821, but commercial production in the United States did not commence until 1925. In 1941, production in the United States was 1.1 million pounds (1 million kg), and it increased steadily to a peak of 763 million pounds (347 million kg) in 1980. Production then decreased steadily through 1996, to 280 million pounds (127 million kg), as the result of environmental restrictions. Production then increased slightly through 1999 and 2003 to 318 million pounds (145 million kg) and 340 million pounds (155 million kg), respectively. Imports declined from the 1980s, when they were typically in the range of 132–140 million pounds (60 to 63 million kg) per year, to an average of 80 million pounds (36 million kg) per year from



## DRY CLEANING AND THE ENVIRONMENT

Fabrics or woven fibers have a number of advantages over the furs, grasses, and shells that were worn prior to their development. Lighter weight and more flexible, they gave people a better variety of choices on how to protect themselves from the weather. Wool, linen, cotton, hemp, and other fibers became widely and reliably available with the domestication of animals and the formation of stable agricultural communities. Although highly automated today, cloth production remains one of civilization's most basic technological advances. Thought to have been developed from the same techniques used in basket making, it is a four-step process.

First the fiber (wool, cotton, etc.) must be collected or harvested. After removal of foreign matter such as dirt, plant, or animal debris, the fibers are then aligned and spun into thread. This thread is then woven into cloth or fabric. Finally, the fabric is cut and shaped into clothing. For almost 10,000 years, that is how fabrics were made, with coloring, blending of fibers, and mechanization introduced as new techniques were developed. One of the most radical advances in cloth production took place in the 1920s and 1930s with the introduction of synthetic fibers such as nylon, rayon, and finally polyester in the 1950s, all made from petroleum products.

### WASHING FABRIC

The development of clothing presented the problem of how to keep it clean. Clothing soiled with dust, grime, body oil, and sweat attracted insects, lost its flexibility and some of its ability to protect against the elements, and became generally uncomfortable and unpleasant to wear. When this happened to an animal skin or grass skirt, the user simply discarded it and went hunting or assembled another. Cloth production, on the other hand, was a highly specialized and time-consuming skill; people did not lightly discard a shirt or blanket that had taken weeks or even months to make.

Ancient Egyptian and Mayan pictographs show people cleaning their clothing in a river or stream, letting the running water carry away the dirt and grime. In many developing countries, clothes are still cleaned in this manner. Agitation helped remove the stains and smells, so clothing was twisted and rubbed, even pounded against rocks. After washing, the cleaned materials were spread out on the grass to dry in the sunshine. Over time, rocks were replaced with corrugated washboards, and the cloths were hung up in the breeze to allow them to dry faster and to prevent insects from infesting them. In water-poor areas where streams were scarce, wash water was placed in tubs and its

solvent effect was increased through the use of soaps, which were lye leached from wood ash and added to fat or extracted from soaproot or yucca root plants.

Warm water was found to increase the effectiveness of soap, so metal washbasins began to be heated over a fire. By the 1700s, the laundry mangle, or clothes wringer, had been invented to press out excess water and smooth the fabrics being washed. This hand-operated mangle was often combined with a similarly operated paddle inside the washing tub. By moving the paddle, cloth could be agitated and mixed with soap remotely and in larger volumes. With the development of the electric motor in the late 1800s, it was not long before both of these manually operated devices had been replaced with the washing machine.

As fabrics and designs became more complex, and the uses of clothing grew to include not only functionality but also appearance and status, a simple soap and water washing was no longer sufficient. Commercial laundries, which began to appear in the 1700s and 1800s, tried a variety of products to remove stains and improve the appearance and feel of fabrics. Gasoline and kerosene excelled at removing food stains such as grease and bodily oil and sweat residues but were dangerous to work with and the final product tricky to wear for a smoker. In the early 1930s, an Atlanta laundry owner, W. J. Stoddard, working with a chemist from the Mellon Institute developed a much less flammable alternative to kerosene and gasoline called Stoddard Solvent or White Solvent. It became the cleaning fluid of choice until the 1950s. A transparent liquid derived from paraffin, Stoddard Solvent was gentle on fabrics and much less flammable than the petroleum hydrocarbons then in use.

### DRY CLEANING

Shortly after World War II, a new class of industrial degreasing compounds began to emerge. Organochlorides were inexpensive, easy to make, and immiscible in water. An organochloride is an organic compound that contains at least one covalently bonded chlorine atom and has widely diverse chemical structures and properties. One, in particular, a chlorinated hydrocarbon named tetrachloroethylene, also called perchloroethylene (PCE), or perc, would prove to be ideal for use in dry cleaning. Starting in the 1950s, perc gradually replaced Stoddard Solvent and today is used almost universally in the dry cleaning of clothes.

Although soap and water is a useful solvent for many clothes, this combination does not work as effectively with some fabrics such as wool or with some stains

such as grease. Dry cleaning is a process that uses a nonwater solvent such as perchloroethylene to remove stains and bodily residues from clothes and fabrics. In dry cleaning, material is washed in perchloroethylene rather than water. After washing, most of the perc, which is easily evaporated, is recovered in an extractor, a type of distillation unit that filters it and allows it to be reused. The clothes are then pressed and are ready to wear. As almost no water is used in the solvent washing process, the term dry cleaning came into use. The sweet odor that is present when the plastic bag is removed from freshly dry cleaned clothes is that of evaporating perc. One U.S. Environmental Protection Agency (EPA) study estimates that there are 35,000 commercial dry cleaning operations in the United States, which process more than 640,000 tons (581,818 metric tons) of clothes annually. In 2006, these dry cleaners, along with industrial degreasing activities, primarily those associated with metalworking and electronics manufacturing, used 20.5 million pounds (9.3 million kg) of perc in their operations.

### **DANGERS OF DRY CLEANING**

As with almost all industrial products or materials that contribute to the quality and convenience of modern life, the use of perc has an environmental consequence. Although perc is physically much safer than those earlier dry cleaning compounds such as gasoline and kerosene, high airborne concentrations of perc (in the 100,000 mcg/m<sup>3</sup> range), especially when encountered in poorly ventilated areas, have an anesthetic effect, causing dizziness, headache, and nausea. If exposure continues, it can lead to difficulty in speaking and walking, unconsciousness, and eventually death. This most often occurs in occupational settings. Perc has been designated as a potential human carcinogen by the U.S. Department of Health and Human Services on the basis of an increase in liver tumors in mice and kidney tumors in male rats from exposure. Other government agencies and many states consider perc more toxic and require it to be managed aggressively in the workplace. Almost 80 percent of the perc discharged into the environment is via the atmosphere.

Although recent improvements in dry cleaning equipment have helped reduce the amount of perc escaping into the air, it is still a commonly detected air pollutant. Concentrations can vary widely with wind direction, speed, and distance from the emission source; several studies in the United States and Canadian urban areas have reported atmospheric ambient perc concentrations in the range of 0.2–9 mcg/m<sup>3</sup>. Higher values were reported near dry cleaners and certain types of waste processing or disposal facilities,

and lower values found in more rural areas. Human health implications associated with the long-term inhalation of perc at these low levels are not known.

Perc released as a liquid enters the soil and has been shown to damage vegetation. It also can be taken up and stored in the fatty tissue of some animals, thus entering the food web. The real risk posed by the release of liquid perc occurs when it enters the groundwater. Perc has a density of 1.6 g/cm<sup>3</sup> and, therefore, tends to move downward through the groundwater and accumulate as pools or pockets on top of the bedrock or less permeable layers. These pools or pockets of perc dense nonaqueous phase liquid (DNAPL) can continue to pollute groundwater for years after the initial spill and overlying contaminated soil have been remediated. DNAPL pools or layers are very difficult to locate and address. Because it is resistant to bacterial degradation and often accumulates far below the land surface, perc DNAPL is not easily recovered by conventional in situ or ex situ soil or groundwater remedial technologies.

The most common way liquid perc was released from dry cleaning operations, prior to today's strict environmental controls, was during the cleaning or maintenance of equipment, when spent or off-spec perc was simply dumped or poured into a storm drain or onto the ground in back of the shop. Also, toward the end of the dry cleaning cycle, perc-containing cleaning fluid is separated from the small amount of water also used in the process via a distillation unit built into the dry cleaning machine. In the past, this water, which contained residual amounts of perc, was often poured down floor drains or out onto the ground. In the more modern equipment being used today, the wash water is evaporated or removed and collected for processing at a hazardous waste disposal facility. Liquid perc also can escape into the environment via spills or seepage from aboveground or underground pipes, storage tanks, broken or damaged machine process lines, or perc-bearing wastes that have been disposed of improperly.

### **AN EXAMPLE FROM NORTH CAROLINA**

The impacts of perc from dry cleaning operations are amply illustrated at the ABC One Hour Cleaners Site located in Jacksonville, Onslow County, North Carolina. This small property is an active dry cleaner located across the street from Camp Lejeune Marine Corps base, and was in business since the early 1950s. Facility operators had followed standard industry practices in effect at that time for management

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of perc wastes and residues. They pumped them into septic tanks, dumped them on the ground, and even used them to fill potholes on the property. In 1984, routine sampling by the U.S. Navy found that three water supply wells owned by Camp Lejeune had been contaminated with perc and its breakdown products trichloroethene (TCE), 1, 2-dichloroethene (DCE), and vinyl chloride. The source of this contamination was quickly traced to the ABC One Hour site, and, because of the widespread extent of the contamination and the number of people potentially impacted by the contaminated water, the dry cleaner was nominated and accepted for inclusion as a Superfund site in 1989.

A groundwater pump-and-treat system was installed on the site and placed into service in 1996 and continues to operate today. This system collects contaminated groundwater emanating from the area under and around the dry cleaner and treats it prior to discharge to a surface water body. It is scheduled to be in operation until groundwater cleanup goals are achieved, possibly by 2015. Contaminated soil containing residual amounts of perc is being addressed through a soil vapor extraction (SVE) system, which became operational in mid-1998. The SVE system is scheduled to function for at least another 10 years, until it has removed enough perc to allow soil to meet cleanup criteria. Investigation and remedial costs to date have been in excess of \$5 million.

### ALTERNATIVES TO PERC (PCE)

The ABC One Hour example is far from unique, and EPA estimates that there are thousands of dry cleaners around the United States that have released perc into the soil or groundwater. Many of these cleanups are being funded through private party insurance claims, while the costs of others are being borne by federal and state taxpayers. Fortunately, the dry cleaning industry is slowly moving away from perc to other cleaning solutions. These include the following.

#### Wet Cleaning

This is a system that uses biodegradable soap and water in combination with computer-controlled dryers and stretching machines to ensure that the fabric retains its natural size and shape. Wet cleaning is reportedly an acceptable alternative for almost all garments labeled "dry clean only," including leather, suede, and silk.

#### Silicone

This process uses siloxane, a combination of silicon, oxygen, and alkane known as decamethyl-cyclopentasiloxane, or D5, as the cleaning solvent. D5 also has a long, safe history of use as a component of cosmetics

and other personal hygiene products such as deodorants and shampoos, among others. The end products of a silicone-based dry cleaning process are sand, water, and carbon dioxide.

#### CO<sub>2</sub>

First developed commercially in the late 1990s, pressurized, liquid CO<sub>2</sub> combined with a surfactant (soap) is used as the dry cleaning solvent. At the end of the cleaning cycle, the CO<sub>2</sub> is recycled, and, if a release occurs, the CO<sub>2</sub> liquid quickly changes, or sublimates, to a common atmospheric gas and is not able to contaminate soil or groundwater. An added advantage is that CO<sub>2</sub> can be formulated without the use of petroleum products.

#### Alternative Petroleum Solvents

These substitute perc with different hydrocarbon solvents (e.g., Exxon D-2000 or Chevron-Phillips Eco-Solv), which are more biodegradable and less likely to contaminate soil and groundwater.

Each of these perc alternatives has its advantages and disadvantages, and all require expensive upgrades to machinery and equipment, in the range of \$100,000 for most operations. This type of capital investment may be beyond the reach of the majority of small dry cleaning operations that operate on thin profit margins in heavily competitive settings. More importantly, consumers will need to adjust their dry cleaning attitudes, as the use of perc alternatives will be more expensive and may not leave clothes as clean as many of us have come to expect.

*See also* DCE; IN SITU GROUNDWATER REMEDIATION; ORGANIC POLLUTANTS; PCE; SUPERFUND SITES; TCE; VINYL CHLORIDE; WATER POLLUTION.

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1992 to 1996 and 36 million pounds (16 million kg) from 1998 to 2000.

### ENVIRONMENTAL RELEASE AND FATE

PCE is mainly released to the environment by evaporation into the air and especially from point sources such as dry cleaners and factories. In the atmosphere, PCE is primarily in the gas phase, where it degrades through photooxidation reactions. The half-life of this process may be as long as two months, allowing it to disperse over broad areas. It may be washed back to the surface through precipitation during this time. PCE released to soil mainly evaporates into the atmosphere. That which penetrates the soil slightly adsorbs to sand and clay particles, resulting in low to moderate mobility. It slowly leaches into the groundwater system and continues to sink into deeper supplies because it is denser than water (as a DNAPL). It appears that PCE undergoes slow biodegradation under anaerobic conditions in 21–150 days. If PCE is released to surface water, most evaporates into the atmosphere. The rest does not biodegrade or adhere to sediments, and hydrolyzation is extremely slow. It is no wonder that PCE is such a common contaminant in groundwater systems, even public supplies that serve large populations. A recent survey found PCE in 38 percent of surface water nationwide.

From 1987 to 1993, during the EPA Toxic Chemical Release Inventory, more than 1 million pounds (0.45 million kg) of PCE was reported as released to the natural environment from industrial sources alone. By far, the state with the largest amount of release was Louisiana, with far lesser amounts from South Carolina, New Hampshire, North Carolina, Illinois, Texas, Ohio, Indiana, Colorado, and Iowa, primarily from the chemical industry, various textiles, and leather products. Total annual PCE releases to the environment (industrial and commercial) decreased from 37.7 million pounds (17 million kg) in 1988 to 3.7 million pounds (1.7 million kg) in 1999, an impressive 10-fold drop.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous adverse health effects from PCE exposure. PCE has been used as an anesthetic, so the first effects are generally on the central nervous system; they include sleepiness, loss of coordination, dizziness, headache, and finally unconsciousness. More serious effects include eye and upper respiratory irritation, kidney and liver malfunction, and even death at a high enough dose. Long-term chronic exposure may produce head-

aches, abdominal discomfort, nausea, constipation, cirrhosis of the liver, hepatitis, nephritis, cardiac arrhythmia, increased spontaneous abortions, menstrual disorders, decreased fertility, and general kidney damage in humans. Animal studies mainly show damage to the liver, kidney, and central nervous system, as well as reproductive effects. The current classification for PCE is in group C-B2, as a possible human carcinogen to probable human carcinogen. Animal studies show a fairly strong link to increased risk of liver and kidney cancer and leukemia. Epidemiological studies on humans link PCE to cancers of the lungs, liver, skin, colon, cervix, larynx, urinary bladder, esophagus, and lymph glands. The problem is that the studies were done on people in the dry cleaning industry, and PCE is not the only potentially dangerous compound that the workers were exposed to on a regular basis. The connection is, therefore, inconclusive with the current information.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies have regulated the amount of public exposure to PCE. The EPA limits PCE in drinking water to five parts per billion (ppb) or less under the Safe Drinking Water Act. They further require that any release of 100 pounds (45.5 kg) or more be reported to the National Response Center. The Occupational Safety and Health Administration (OSHA) limits exposure of workers to 100 parts per million (ppm) (PEL) over an eight-hour-day, 40-hour workweek and a peak exposure of 300 ppm for a maximum of five minutes. The National Institute of Occupational Safety and Health (NIOSH) has set a designation of immediately dangerous to life and health (IDLH) for any exposure of 150 ppm or more. In their National Occupational Hazard Survey of 1972–74, NIOSH estimated that 1.6 million workers were exposed to PCE. In their National Occupational Exposure Survey of 1981–83, the number dropped to 566,000, and a 1994 industry survey further reduced the number to 450,000 workers.

*See also* ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**PCP (pentachlorophenol)** Pentachlorophenol is not the PCP that is used as an illegal drug; rather, it is a deadly pesticide. PCP was widely used in wood preservation and as one of the most common pesticides, but it has an odd environmental history. It commonly contains small amounts of dioxin, hexachlorobenzene (HCB), and furan even at technical grade. Early health problems associated with PCP were attributed to these other very dangerous substances. It took years of study to show that the PCP was also dangerous. As a result, PCP was listed as a restricted use pesticide (RUP) for most applications and banned from sale to the general public in 1984. After the restrictions, its use was greatly reduced both domestically and internationally, and it was banned altogether in several countries. PCP is also known as Penchlorol, Dowicide 7, Permasan, Fungifen, Grundier arbezol, Lauxtol, Liroprem, Chlon, Dura Treet II, Santophen 20, Woodtreat, Penta Ready, Penta WR, Forpen-50, Ontrack WE Herbicide, Ortho Triox, Osmose WPC, Watershed WP, and Weed and Brush KillerH. PCP has been identified in 313 of the first 1,585 U.S. Environmental Protection Agency (EPA)-designated Superfund sites (National Priorities List) in which it was tested. It ranks 45th of the 275 most dangerous pollutants on the 2007 CERCLA Priority List of Hazardous Substances. It is, therefore, regarded as one of the more hazardous pesticides, primarily by virtue of its toxicity, persistence, and extremely wide distribution.

## PROPERTIES, USE, AND PRODUCTION

PCP is a synthetic organochloride biocide in the category of semivolatile, chlorinated phenolic compounds. It occurs as colorless or tan to white needlelike crystals with a benzenelike smell. PCP is almost always mixed with other organic compounds. Even at technical grade, it contains 4–12 percent other chlorinated phenols and tetra-, hexa-, and octochlorodibenzo-p-dioxins (dioxin), polychlorinated dibenzofurans (furan), and chlorobenzenes (benzene), among other compounds. PCP has been available in blocks, flakes, granules, liquid concentrates, wettable powders, or ready-to-use petroleum solutions. PCP is primarily used as an insecticide (especially for termites), a fungicide, an herbicide, a molluscicide, a mossicide, an algicide, a disinfectant, a biocide in industrial water systems, and an ingredient in antifouling paint. It is primarily used as an industrial wood preservative for utility poles, cross arms, fence posts, railroad ties, and wharf pilings, as well as consumer products such as boats and log homes. Other uses include as a seed treating agent for beans; as a leather and textile treatment; in paper coatings, latex paint, food can seals, cooling tower additive, and food storage containers; and as a preservative for glues, starches, and photographic papers. About 10 percent of PCP is used to produce Na-PCP.

PCP was introduced as a wood preservative in 1936, and, by 1947, nearly 3,520 tons (3,200 metric tons) was used in the United States alone. By 1977, production was as much as 50 million pounds (22.7 million kg) per year but soon began to decline because of the health concerns and impending restrictions. In 1983, production was still at 45 million pounds (20.5 million kg), to 35 million pounds (15.9 million kg) in 1985, the year after the 1984 restrictions. By 2002, domestic production had dropped to 11 million pounds (5 million kg), with much of it exported.

## ENVIRONMENTAL RELEASE AND FATE

PCP is most commonly released to soil and air as a nonpoint pollutant, as are most pesticides. Through spills and leaks during manufacturing, transport, and storage, or from improper disposal, PCP may also be a point source pollutant. If released into the soil, PCP tends to bind to soil and sediment particles as a function of higher oxidation and lower pH and has low mobility. In this case, the PCP is removed primarily by biodegradation under anaerobic conditions, with a removal half-life of weeks to months (average 45 days) after a two- to three-week period

of microbial acclimation to it. Under certain conditions, however, it may remain as much as five years. If the soil is reduced and basic, PCP may be moderately mobile and leach into the groundwater system. It has been found in water from wells in California, Oregon, and Minnesota that were not near waste sites. The rate of degradation is concentration dependent by anaerobic microbial activity, averaging 38 days for three parts per million (ppm) and 57 days for 5 ppm. If released to surface water, PCP mainly binds to suspended particles and settles into the sediment. Some biodegradation and photodegradation happen at the surface and may be quick (hours to days) but account for very little of the release. That which remains in the sediment degrades very slowly and as a function of concentration, similarly to degradation in groundwater. PCP can evaporate from surfaces of treated wood. In air, PCP is degraded by reaction with photochemically produced hydroxyl radicals and by photolysis.

PCP also has a strong effect on ecological systems. Although it is slightly to nearly nontoxic to birds, PCP is highly to very highly toxic to most species of fish. It is also toxic to mammals. Farm animals that licked PCP-treated wood became sick and, in some cases, died. PCP is also toxic to strongly toxic to plants and can be taken up and accumulated in some plant species. PCP is very toxic to insects, fungus, moss, and aquatic invertebrates.

In the EPA 1987–93 Toxic Chemical Release Inventory, reported industrial releases of PCP totaled 98,480 pounds (44,764 kg) to land and water, 80 percent of which was to land, with a total release of 991,211 pounds (450,550 kg). The top state by far was Nevada, followed distantly by Oregon, Washington, Arizona, and Georgia, primarily from the explosives, wood preserving, and chemical industries. In 1998, the total release was 271,495 pounds (123,406 kg), primarily in Idaho, followed distantly by Alabama, with minor amounts in Oregon, Washington, and Texas. By the time of the 2005 Toxics Release Inventory, only 16,933 pounds (7,697 kg) of PCP was reported released by industry that year.

### HEALTH EFFECTS FROM EXPOSURE

PCP is considered to be moderately to highly toxic. Exposure can have many sources in everyday life, including by eating fruits and vegetables. Once in the body, it can be very persistent with an elimination half-life of as long as 20 days. This persistence means that short-term exposure can produce long-term effects. Short-term exposure to PCP in even small amounts by inhalation, ingestion, and even

dermal contact can result in poisoning. Symptoms may include dizziness, mental confusion, restlessness, sweating, hyperthermia with high fever; eye, nose, and throat irritation; difficulty in breathing; muscle weakness, spasms, and tremors; chest and abdominal pain; and, if the dose is high enough, death by respiratory failure. Long-term exposure quickly leads to liver, kidney, blood (anemia), and nervous system damage, as well as skin rashes including chloracne; and to weight loss, permanent vision damage, fatigue, weakness, bronchitis, and circulatory obstruction, including heart failure, and excessive sweating. The chloracne may be the result of dioxin poisoning. PCP may also damage developing fetuses, increasing the risk of miscarriages, low birth weight, and birth defects including skeletal abnormalities. Sudden infant death syndrome has also been reported in some cases.

PCP is considered to be possibly carcinogenic to humans (group 2B) by the International Agency for Research on Cancer (IARC) and to be a probable human carcinogen (group B2) by the EPA. PCP has been linked to increased incidence of Hodgkin's disease, acute leukemia, and soft tissue cancer of the lip, mouth, and pharynx, among other sites in humans, and cancers of the liver, adrenal gland, and spleen in laboratory animals. Although PCP products were long known to be associated with increased cancer, it was not clear whether the culprit was an impurity such as dioxin, which is a known carcinogen, or whether PCP itself was the cause.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies regulate worker and general exposure to PCP as the result of these health risks. The EPA limits the amount of PCP in drinking water to one part per billion (ppb) under the Safe Drinking Water Act and requires the reporting of any environmental release of one pound (0.45 kg) or more to the National Response Center. The Occupational Safety and Health Administration (OSHA) restricts the amount of PCP in workplace air (PEL) to 0.5 mg per cubic meter for an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) has set the same general exposure limit (REL) as OSHA and a designation of immediately dangerous to life and health (IDLH) for any exposure of 2.5 mg of PCP per cubic meter of workplace air. PCP was severely restricted for most applications in Europe by the early 1980s and in the United States by 1984. It is completely banned in Germany, Finland, and Sweden, among other countries.

See also BENZENE; DIOXIN; FURAN; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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#### **Pennsylvania coal mine fires Centralia, Pennsylvania (May 1962–present) Air Pollution**

There are stories that as the result of a lot of garbage after a May Day or Memorial Day parade in Centralia, Pennsylvania, municipal workers decided to burn the refuse in the newly opened town dump in an abandoned coal strip mine. Others say that it was the act of a careless trash hauler who dumped smoldering refuse in the town dump. Whether an event was the reason to start the fire or garbage was just piling up too fast in the new dump is unclear. What is clear is that the fire spread into a mine shaft off the strip-mined area and ignited a coal seam underground. With enough air remaining in the maze of old mine shafts that exist in this coal mining area, the fire was able to spread unchecked underground. This simple act of burning a pile of garbage would initiate an incident that would doom the town of Centralia and threaten all of the surrounding towns. The fire still burns today, and now it can never be extinguished.

#### **THE TOWN OF CENTRALIA**

Centralia was in Columbia County, Pennsylvania, in the heart of coal country. The first record of a settlement in Centralia, then known as Centreville, was in 1841, but the town was not incorporated as Centralia borough until 1866. The whole reason for the existence of the settlement was to mine coal. In 1854, Alexander Rea, a civil engineer for the Locust Mountain Coal and Iron Company, developed the plan for the physical layout of the town. Activists of the Molly Maguires, an Irish underground miner terrorist organization who frequented the area during the 1860s and 1870s, murdered Rea in 1868. Three men were hanged in 1878 for the crime.

Perhaps this tragic beginning doomed the town, but during most of its history no one would have suspected that it was doomed, because the town flourished. Employment was high thanks to the coal mining industry, which kept it relatively prosperous. A major rail line served the town, and there was an active downtown area with a variety of businesses and shops. The population remained above 2,000 residents with 500–600 just outside of town throughout its history. The peak population was 2,761 immediately before the fire began. This would change quickly.

#### **THE UNDERGROUND FIRE**

The sequence of events that would lead to the demise of Centralia began in early 1962, when the town council decided to abandon the old and overfilled town landfill for a new location in an old strip mine. The mine pit had numerous holes in it where it intersected with old underground mines and where seams were followed but abandoned. By Pennsylvania law, these openings of all kinds had to be sealed before the pit could be used as a landfill to prevent surface leakage, including fires, into the underground system. The town performed the required sealing and was issued a permit by the state. They began using the pit as a landfill as soon as it was open.

The fateful incident of burning the trash took place at the end of May 1962. It is reported to have been conducted by volunteer firemen hired by the town, but municipal workers were probably involved as well. The fire, referred to as "the Incident" by locals, was extinguished, or so they thought, after it was done. The fire flared up a few days later, and the fire department extinguished it again. It was at this point that the one unsealed hole in the pit floor was discovered beneath the burning garbage. This one hole was the gateway to a century's worth of interconnected mine shafts, and the fire exploited it.





Smoke from an underground coal mine fire vents near Centralia, Pennsylvania. (© Leif Skoogfors/CORBIS)

The fire quickly spread through the abandoned tunnels, burning both coal dust and debris and the remaining coal in the walls. There was and is not enough oxygen in the mine for a complete burn of the coal. As a result, the main pollutant being emitted is carbon monoxide. Other pollutants also result from partial burning but rarely are emitted at the surface. These pollutants include particulate, polycyclic aromatic hydrocarbons (PAHs), benzene, and others. Residents began complaining of symptoms of carbon monoxide poisoning soon after the fire began. There was a rash of unexplained headaches, nausea, and flulike symptoms that would strike entire families for extended periods. There are reports that the Pennsylvania Department of Environmental Resources began drilling monitoring wells to observe the progress of the fire as early as July 1962.

Through the years, the fire spread, and its evidence became apparent. By May 1969, the first three families were relocated from Centralia because their homes were no longer safe. In 1979, a gas station owner noticed that the gasoline in his underground tanks seemed warm. He lowered a thermometer into the tank to find that the gasoline was 172°F (77.8°C). In 1981, the situation was

called to national attention when a sinkhole suddenly opened under the feet of a 12-year-old boy. The hole was four feet (1.2 m) wide and 150 feet (45 m) deep; the fall into it would have killed him, but he grabbed some roots at the last minute. Luckily, his older cousin was with him and pulled him out of the hole. Many other such sinkholes began opening in other parts of the town as well.

### CONFRONTING THE BLAZE

There were many efforts over the years to confront the fire, but none of them was particularly concerted or effective. The first attempt to stop the spread was in 1969, seven years after it had begun. Trenches and clay caps were installed around the area where the fire started, but the project was not well planned or executed and ultimately never completed. The chance for success was poor anyway because the fire had spread too far by then.

By the time the situation had attracted public attention in 1981, some \$7 million had been spent to extinguish the fire. The mines had been flushed with water and fly ash, excavated to remove the burning material, trenched and backfilled, and drilled numerous times to delineate the extent of the fire. In



response to the public attention, in 1983, the state proposed an ambitious plan to dig a trench 500 feet (154 m) deep around the town to contain the fire and to condemn and purchase all of the homes and businesses. The total cost of the plan was \$660 million, and there was no guarantee that it would work. In the end, the U.S. Congress allocated \$42 million to buy out the residents and decided to let the fire burn itself out. They hoped that it would not spread.

The process of purchasing the homes and businesses began immediately, and the last purchase of the plan was for 26 homes just west of Centralia in 1991. In the following year, the state of Pennsylvania claimed eminent domain and condemned all remaining homes. The main thoroughfare in town, Route 61, began to crack and melt in several places, and after several unsuccessful attempts at repair, it was closed in the mid-1990s and detoured around the area. In 2002, the U.S. Postal Service revoked the borough's zip code.

Today, the fire is estimated to underlie an area of 400 acres (162 ha) and to be growing daily. There are several warning signs posted around the area and several metal steam vents. Unhealthy smoke and gas escape from surface vents, both constructed vents and holes in the ground, in various locations, and there are sinkholes in several spots. There are no plans to extinguish the fire, and it may take as much as 250 years to burn out on its own.

### COAL MINE FIRES: A GLOBAL PROBLEM

The upheaval of the entire population of the town of Centralia was an emotional and economic crisis for the residents. This, however, is not the only coal mine fire in the United States or even in Pennsylvania. The towns of Carbondale, Laurel Run, and Vanderbilt, Pennsylvania, may come to the same end as Centralia. There are literally hundreds of coal mine fires in American coal mines, many of which threaten to produce the same results as in Centralia in other communities. They are already degrading the air quality in these communities to unhealthy levels in some cases. The United States is not the only country with coal mine fires; they are an international problem. Australia has an underground coal fire that is estimated to have been burning for 6,000 years, the oldest of its kind. Indonesia is beset with extensive coal mine fires that foul the air to the point where resulting respiratory ailments have become epidemic in some areas. The worst case of coal mine fires is in China, where some 20–200 million tons (18–180 million metric tons) of coal is consumed each year. It is

estimated that these fires alone make up 1 percent of the global fossil fuel consumption and thereby contribute to carbon dioxide emissions and global warming.

See also AIR POLLUTION; CARBON MONOXIDE; PAH; PARTICULATE.

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**perchlorate** One of the most controversial and vigorous of the current environmental debates centers around the compound perchlorate. Even though there are no regulations or even definitive health studies demonstrating a danger to the environment or public health, high-profile politicians debate the perchlorate controversy in the U.S. Congress and in the press. Entire communities have filed lawsuits against manufacturers and consumers, claiming crises in public health as a result of exposure to perchlorate. Clearly, with no regulations or even reliable health studies, this debate is relatively new. This is surprising, considering that perchlorate has been used extensively since the 1950s. The catalyst for the debate is the discovery that more than 20 million Americans are regularly exposed to perchlorate in their drinking water. Couple this wide distribution and exposure with a theoretical possibility of health problems and the controversy was born.

## PROPERTIES, USE, AND PRODUCTION

The term *perchlorate* really just refers to the ion  $\text{ClO}_4^-$ . What is meant by the term is perchlorate salt, which is produced by the reaction of perchloric acid with some other compound. There are many perchlorate salts including ammonium perchlorate ( $\text{NH}_4\text{ClO}_4$ ), cesium perchlorate ( $\text{CsClO}_4$ ), lithium perchlorate ( $\text{LiClO}_4$ ), magnesium perchlorate ( $\text{Mg}(\text{ClO}_4)_2$ ), potassium perchlorate ( $\text{KClO}_4$ ), rubidium perchlorate ( $\text{RbClO}_4$ ), silver perchlorate ( $\text{AgClO}_4$ ), and sodium perchlorate ( $\text{NaClO}_4$ ), among others. They can be synthesized or occur naturally in some arid areas. Of these salts, the compound of greatest interest is ammonium perchlorate because it is the primary component of solid rocket and missile fuels and propellants, among other fuels. It first went into production in the 1940s for purely military purposes. In addition to rockets, it was used in explosives, mortars, grenades, and flares. It is estimated that more than 90 percent of all ammonium perchlorate produced was either used in military applications or by the aerospace industry (including fuel for the Space Shuttle). The remaining 10 percent was used in conjunction with other perchlorates (primarily potassium and sodium) in pyrotechnics and fireworks, blasting agents, matches, lubricating oil, nuclear reactors, electronic tubes, paints and enamels, tanning and leather finishing, air bags for automobiles, and certain types of fertilizers. Perchlorate occurs naturally in some potassium nitrate fertilizers from Chile, which were extensively produced and imported to the United States in the early 20th century. Lithium perchlorate is used for oxygen candles that produce lifesaving oxygen for miners and other workers during emergencies. Potassium perchlorate is used in protective breathing devices in the U.S. Navy and U.S. Air National Guard.

## ENVIRONMENTAL RELEASE AND FATE

Perchlorate is primarily a point source pollutant from military installations (air force, navy, and some army), disposal sites, and manufacturing plants. It is also a nonpoint source pollutant from fertilizers and fallout from pyrotechnics and aerospace and military applications. As a result of military weapons testing and improper dumping of perchlorate in Arizona, California, and Nevada, most of the drinking water in those states is tainted including the water in the Colorado River, which supplies some 20 million people. It is not, however, restricted to these states. Perchlorate has been found in water from 25 states, and it is expected that locations in 43 states will be identified. It is known to have been produced,

stored, or used at more than 150 sites in 36 states, many of which have yet to be tested. There remain at least 63 military sites in 32 states where rockets, missiles, and munitions were used where testing for perchlorates has yet to be done.

When perchlorate is released into the soil, it adheres only weakly to soil particles. For this reason and because it is highly soluble in water, it is highly mobile in soil and able to be readily leached into the groundwater system. Once in groundwater or surface water, it is relatively inert, rarely undergoing chemical reactions that might remove it. It also tends to stay in solution. For these reasons, it is very persistent in water, able to remain a threat for extended periods. It is even able to remain in solution through uptake into plants. It has been detected in lettuce, cow's milk, various vegetables, and human breast milk. Preliminary bioaccumulation factors for perchlorate in leafy vegetables are as much as 65 times ambient water levels, thus increasing the risk.

## HEALTH EFFECTS FROM EXPOSURE

Strangely, potassium perchlorate was used in great quantity in the 1950s and 1960s to treat hyperthyroidism resulting from Graves' disease, and it is still used to determine thyroid hormone production in some clinical settings. It is strange because it is the thyroid that is most at risk from perchlorate exposure. Perchlorate interferes with iodine uptake into the thyroid gland, and iodine is an essential component of hormones from the thyroid; thus, its function can be disrupted. The thyroid gland regulates metabolism in adults and children alike. In children, however, it is also important in development, which can be delayed by thyroid malfunction. The real danger is to pregnant mothers, because thyroid malfunction can impact the fetus, causing behavioral problems; increased mental retardation; loss of hearing and speech; delayed development, including deficits in motor skills; and decreased learning capacity, including significantly reduced IQ in offspring. There is also evidence that perchlorate exposure may increase the risk of thyroid cancer. There is a possibility that perchlorate works synergistically with other compounds such as nitrates to worsen the health effects.

## REGULATIONS ON HUMAN EXPOSURE

At this point, there are no regulations for environmental exposure of perchlorate, but there is an enormous amount of activity in the federal regulatory agencies, and regulations were expected by 2008.

To date, the U.S. Environmental Protection Agency (EPA) has established an official reference dose of 0.0007 mg of perchlorate per kilogram of body weight per day, though the National Research Council considers it to be too stringent. With this reference dose, the limit of perchlorate in drinking water would be set at 25 parts per billion (ppb) under the Safe Drinking Water Act. California, however, one of the most strongly impacted states, considers this level too lax and has an advisory level of 2–6 ppb. Recently, the EPA has been considering a range of 4–18 ppb in a draft version.

*See also* INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; MILITARY FACILITIES AND THE ENVIRONMENT.

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**pesticides** Pesticides have a reputation both as a boon and as a scourge in modern society. The best example of this conflicting reputation is dichlorodiphenyltrichloroethane (DDT), the most notorious of the pesticides. Although DDT was invented in 1874, its properties as a pesticide were not discovered until 1939. This discovery was heralded as one of the greatest in the history of modern civilization. In recognition of this work, Paul Muller, the discoverer of these properties, was later awarded the Nobel Prize. In contrast, in her book *Silent Spring*, Rachel Carson specifically targeted DDT as the most

dangerous chemical in the environment. Her efforts sparked the American environmental movement. As a result, the U.S. Environmental Protection Agency (EPA) was created, and one of its early and most heralded efforts was to ban DDT.

Pesticides can be credited for a large part of the vast success of the human race in the 19th and 20th centuries. DDT alone essentially banished typhus and malaria from Europe and North America and even started the fight in other areas. The pesticides control disease-carrying insects and vermin, thereby limiting human contact. Estimates of the number of people whose lives have been saved by this indirect effect of pesticides are in the hundreds of millions. In addition, pesticides control the insects, plants, vermin, and other threats that consume and destroy the food supplies on which humans depend. The ability of modern civilization to feed the burgeoning human population of the past two centuries is certainly to a large degree the result of the effectiveness of pesticides. Pesticides protect the seeds, plants, and produce throughout the growing cycle and greatly enhance the yields. Agricultural efficiency has increased around the world as a result of pesticides, in some cases on the scale of orders of magnitude.

To achieve this efficiency, huge amounts of pesticides must be manufactured and applied to crops. Some classification systems consider the chemicals used in water purification to be pesticides. If so, they constitute about half of all pesticides used. For this discussion, only conventional pesticides are considered in detail. These are the pesticides that are applied directly to food, seeds, or living plants (and/or their surroundings) to control specific target organisms. This use constitutes about 23.3 percent of all pesticide application in the United States, or roughly 1.24 billion pounds (563 million kg) per year. Considering that global consumption of conventional pesticides is about 5.7 billion pounds (2.6 million metric tons), the U.S. part is about 20 percent.

If pesticide application had been handled judiciously, the environmental movement might have been longer in getting established. The problem was that they were applied almost indiscriminantly in virtually all agricultural areas. They began not only to control the pests but also to affect desirable species negatively. They entered soils, water, and air and bioaccumulated and biomagnified in nontarget species. By the 1960s, they were regularly being found in foods to which they had not been applied. There was an alarming increase in pesticide residues in human mother's milk, to the point at which it was recommended that mothers in some areas avoid

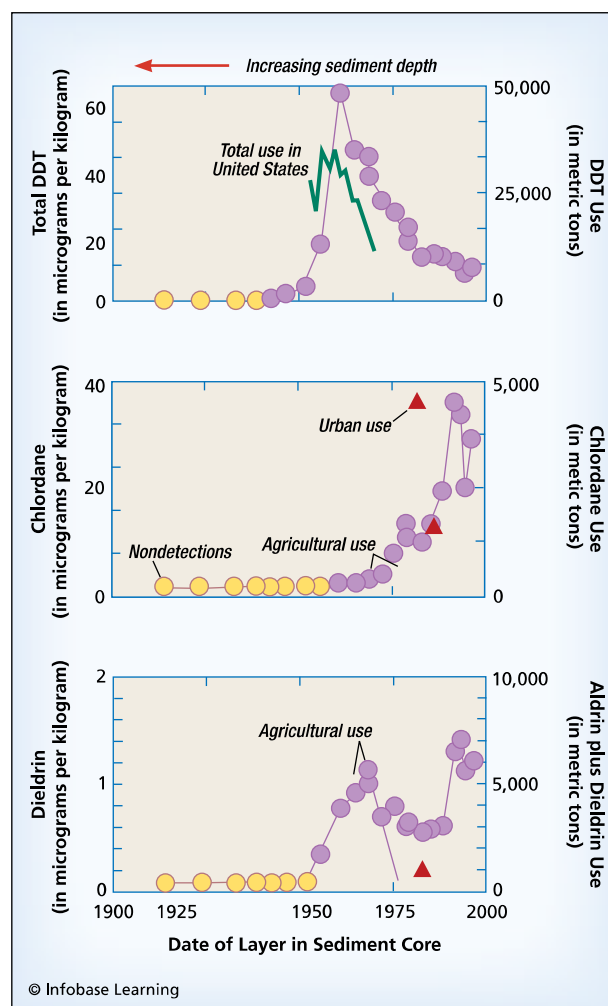
nursing. Pesticides were carried so far into the atmosphere that they were discovered in glacial ice. It is to the credit of the work of the environmentalists that governmental efforts to reduce pesticides through the 1970s and 1980s significantly reduced pesticide residues in milk, to the point where there is little danger from them. Recently, the problems with pesticides have shifted to the severe damage they cause to beneficial species. These are significant enough to undermine the beneficial aspects of the pesticide in some cases.

### CLASSIFICATION OF PESTICIDES

There are numerous classification systems for pesticides. The main system of classification is based upon the pest to be controlled. The primary type of pesticide is an insecticide, in which the primary targets are insects. Insecticides are used in agricultural applications, as large-scale preventative measures, and in individual applications around homes. In agricultural applications, they can be applied to seeds, to soil, or directly to plants either by spraying or from airplanes through crop dusting. Large-scale preventative applications usually involve spraying and are usually done to control destructive or potentially disease-bearing insects such as mosquitoes. Household insecticides are typically used to control insects that are health threats such as wasps and cockroaches or threats to property such as termites and carpenter ants. Household use of insecticides must be carefully monitored because of the potential threat of accidental poisoning.

Herbicides (including algicides and fungicides) are generally considered separately from pesticides in most classifications but are briefly included here because they are not always separated. Herbicides control the growth of unwanted vegetation with minimal damage to the surrounding plants and animals. They can be used in agricultural applications, especially with regard to ornamental plants, and household applications. In agriculture, they control the growth of plants that could compete with the crops for resources. The most widespread use of herbicide is on lawns and around ornamental plants at private residences. This application spreads herbicide throughout most suburban areas in an effort to remove weeds that might compete with grass. Herbicides can also be sprayed on undergrowth along roadsides, on plants that threaten health and safety such as poison ivy, and in lakes and ponds to control weeds.

Other pesticides include fungicides to control fungal growth on seeds, crops, and ornamental plants. Rodenticides are used to control mouse and rat pop-



**Graphs of the concentrations of three common pesticides (left side) from a sediment core taken from White Rock Lake, Texas, and total use (right side) versus depth/time before present in years from 1900 to 2000. It shows continued accumulation of these pesticides decades after their last use. DDT and dieldrin were banned in 1972 and 1974, respectively, and most uses of chlordane were stopped in 1983.**

ulations. Avaricides are used to control unwanted bird populations. These and other specialized pesticides can be used in agricultural and private home applications, but their use is volumetrically minor relative to that of insecticides and herbicides.

There are also chemical classifications of pesticides. They can be inorganic, organic, and biological agents. Inorganic pesticides are compounds that contain lead, mercury, copper, arsenic, or the like. They may be highly toxic and are virtually indestructible, remaining active indefinitely. They can be used as seed coatings but are commonly used on wood and in other nonedible applications. Biological agents are living organisms or toxins derived from them that can be used in place of conven-



tional pesticides. They may be insects or bacteria that remove unwanted species. They are commonly used in organic gardening.

Organic pesticides are generally divided into the following four main types:

1. Organophosphorus: most common are parathion, malathion, and dichlorvos.
2. Carbamate: most common are carbaryl (a.k.a. Sevin), aldicarb, and carbofuran.
3. Organochlorine: most common are chlordane, Toxaphene, heptachlor, DDT, methoxychlor, Endrin, aldrin, dieldrin, and lindane.
4. Botanical and others: typical examples are nicotine (from tobacco), pyrethrum (from chrysanthemums), and rotenone (root extract).

All of these types have different properties and characteristics and are designed to control specific species under a specific set of conditions. These properties include toxicity, selectivity, chemical stability, persistence in the environment, mobility, and physical form. Organophosphorus pesticides are generally extremely toxic (10–100 times more powerful than all others) but generally break down very quickly in the natural environment. They attack the nervous system by inhibiting cholinesterase, causing rapid death in insects, birds, mammals, fish, and humans alike. Their development formed the precursor to the highly toxic nerve gas weaponry during World War II. Carbamates can be moderately to very highly toxic but are only moderately persistent at best and are relatively mobile. Many compounds share the characteristics of organophosphates in terms of action and toxicity, but others are less potent and more persistent. Organochlorine pesticides are highly toxic and highly persistent in the environment, remaining for several decades, in some cases. Several have been banned from sale and usage because they were determined to be a threat to the environment or human health. Botanicals, or natural organic pesticides, are most commonly used by organic gardeners and environmentalists because they are the least damaging to the environment. They are also the least effective of the organic pesticides.

Fumigants are also organic pesticides. They are small-molecule compounds that evaporate easily and then penetrate the pores of a variety of materials, thus protecting their interiors. Examples of fumigants include carbon tetrachloride, carbon disulfide, ethylene dichloride, and methylene bromide. They

are moderately to highly toxic, and, as gases, they are very dangerous to work with; as a result, many have been restricted or banned.

## PESTICIDES IN THE ENVIRONMENT

Pesticides were designed to kill living organisms. Aside from the natural pesticides such as many of the botanicals, pesticides are very harsh on the environment. The degree to which they damage the environment depends mainly upon toxicity and persistence, but several other factors related to their mobility control the degree to which they will be spread from the point of application. The farther the pesticide is spread from the application site, the more likely it is to affect the environment.

Upon release, pesticides may either evaporate into the air as a vapor or enter the soil/water system as a solid or liquid depending upon the vapor pressure. That which enters the air may break down by photodegradation through exposure to sunlight or interaction with air pollutants. If it does not break down, it may settle to the ground as fallout, either directly or by attaching itself to dust particles, or it may be washed out by precipitation. Pesticides may travel long distances in this way to areas that should be remote from pesticides such as glacial ice in Antarctica or the sands of the Sahara.

Resistance to chemical breakdown is persistence. It is measured in removal half-life, which is the time required to remove half of the mass of the pesticide from the environment either by physical removal or by chemical/biological breakdown. Chemical breakdown occurs through the chemical reaction of the pesticide with air, soil, or water to produce less toxic by-products. Biological removal is typically accomplished through microbial activity either in the presence of oxygen (aerobic) or without it (anaerobic). These microbes dissociate the pesticide to use the carbon atoms as nutrients. Persistent pesticides are usually toxic to the soil and water microbes. If the half-life of the pesticide is 30 days or less, it is considered to be of low persistence. Examples of low-persistence pesticides are aldicarb, malathion, and methyl parathion. If the half-life of the pesticide is 30–100 days, it is considered to be of moderate-persistence. Examples of moderate-persistence pesticides include aldrin, atrazine, carbofuran, diazinon, endrin, heptachlor, parathion, and phorate. High-persistence pesticides have half-lives greater than 100 days and include such compounds as trichloroethane (TCA), chlordane, paraquat, lindane, and DDT. More persistent pesticides can be spread farther from the point of application without breaking down.

Mobility of pesticides is another property that determines their impact on the environment. Once released into the soil, pesticides may adhere to soil particles in a process called adsorption. The degree to which the pesticide is adsorbed determines its mobility. Pesticides that are adsorbed to soil most commonly attach themselves to organic particles or clays. They are fixed and immobile. Pesticides that do not attach to these particles are considered mobile and can leach or percolate into the groundwater system. There they can spread long distances and affect human activities, as well as the natural environment. Degree of solubility in water is the main factor in the degree of mobility of a pesticide. In sandy soils, even pesticides with a tendency toward immobility may be mobile and leach into the groundwater system with the mobile components. Another process that mobilizes immobile pesticides is erosion. Surface runoff can erode soil with pesticide adsorbed to it and carry it into the surface water system. There, it may be carried in suspension for great distances. Wind may perform the same function in arid regions.

The final major factor in the effect of pesticide on the environment is whether it is systemic or not. Some pesticides are absorbed through the root systems and distributed throughout the plant, whereas others are simply topical. Those that are taken up by the plant are considered systemic. Once they are sprayed on soil, residues of systemic pesticides may be found in the plants in those soils for many years after the application has ceased. They continue to absorb the pesticide from the soil preferentially. Nonsystemic pesticides are only effective when they are on the surface of the plant and do not participate in the system after they have been washed off or harvested.

### REGULATION OF PESTICIDES

To address the moderate to extreme toxicity of pesticides, their distribution, application, and human and environmental exposure are highly controlled both by the U.S. local and federal governments and by international governments. In the United States, there are at least 14 federal acts regulating some part of the manufacture, registration, distribution, use, consumption, and disposal of pesticides. The primary act in this regulation is the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), which governs the national registration, distribution, sale, and use of pesticides. Environmental and human exposure is primarily regulated by the Clean Air and Water Act and the Safe Drinking Water Act. All of the statutes of these acts are enforced by the U.S. Environmental Protection Agency (EPA). Individual states may

choose to impose more stringent standards than the federal government to address some local concern or the will of its residents. California typically has the most stringent regulations in the United States.

For new pesticides put on the market, the EPA requires justification that there is economic need for it as well as evidence of its safety. They may require up to 70 individual tests on the new product, which can cost the company millions of dollars. These tests demonstrate safety to humans and the environment, and the fate of the pesticide once it enters the environment. If a pesticide is particularly dangerous, it is assigned a restricted use pesticide (RUP) status, which requires special handling by certified professionals. It typically takes six to nine years to move a new pesticide from laboratory to market including at least two to three years to gain EPA registration approval. The EPA began requiring these extensive data on pesticides in 1978. Since then, they have registered 130 new active ingredients in pesticides, with 10–15 new registrations per year.

Pesticides that were developed before the current stringent requirements have gone through a reregistration process under EPA. Old pesticides had to be tested and evaluated at nearly the same level as new pesticides. Reregistration turned into a massive process that was proceeding so slowly that in 1988 amendments were added to FIFRA requiring that the entire reregistration process be complete by 1997. During this review process, there were several actions that the EPA could take for particularly dangerous pesticides. A special review was called to modify or deny registration. The result of the special review was either cancellation of the pesticide or registration under different terms. If the pesticide posed an imminent threat to human health or the environment, its sale and use would be suspended during the special review process.

The EPA also sets maximal legal limits for pesticides on foods and in animal feed available for sale in the United States. This authority is granted to the EPA under section 408 and/or 409 of the Federal Food, Drug and Cosmetic Act (FDCA). Under this authority, the EPA has approved about 300 pesticides for food uses; about 200 of them are in common use.

### CURRENT PROBLEMS WITH PESTICIDES

There are three major problems with pesticides at this time: collateral damage to beneficial species, imports of food from countries with different regulations, and evolving immunities to effective pesticides. The ultimate driver of problems with pesticides is the overwhelming demand of the burgeon-

ing human population on resources of the Earth as well as perhaps some greed among food producers. The demand for food is so great that the efficiency of farmland is pressed to its limit in many areas. Efficiency not only means deriving the maximal yield from crops, which involves overuse of fertilizers, but also converting these crops into sales of market items. The loss of crops to pests in this frenzied economy is almost unacceptable. As a result, farmers tend to overuse pesticides as well. Further, the demand of homeowners and Americans in general for well-landscaped and insect-free communities and properties further adds to the problem of excess pesticides in the environment.

The problem of collateral damage to beneficial species has been projected as the downfall of human civilization by some. Not only do pesticides kill the target insects, they also kill many insects and other small organisms that form the base of the food chain. As their populations are reduced, their predators have less food and their population is reduced, as are the organisms that prey upon them. Considering that humans are at the top of the food chain, this sequence of events eventually leads to food shortages. This problem has been occurring relatively unchecked or marginally checked for decades. Even more dangerous is the damage to beneficial species on which we depend. Chief among these are the bees. The vast majority of the pollination of flowering plants, trees, and shrubs is accomplished by bees. The pollination is necessary for the growth of fruits and nuts. The bee populations steadily declined throughout the second half of the 20th century. The North American bee population began to go into crisis in 2004, when a strange syndrome called colony collapse disorder (CCD) caused the destruction of entire colonies. By 2007, North America lost one-third of the bee population in one year. CCD has been blamed on parasites and disease, as well as a new pesticide called imidacloprid. Even if the cause is a disease or parasite, it is possible that the declining health of bees over the years of pesticide exposure, as well as this new highly toxic pesticide, made them susceptible to it. In any event, the elimination of bees has been predicted to herald the destruction of mankind.

Concurrently with the loss of beneficial species, evolutionary adaptations have occurred in the target species that improve their resistance to common pesticides. Not only is there a decline in the insects that help humans, there is an increase in those that do not. Insects such as cockroaches, fleas, ticks, ants, and termites now resist poisoning in significant numbers. New pesticides are being developed in great haste to combat this problem, but they pose new threats to the beneficial species.

See also AGRICULTURE AND POLLUTION; ALDRIN/ DIELDRIN; CARBOFURAN; CARBON TETRACHLORIDE; CARSON, RACHEL; CHLORDANE; DDT; DIAZINON; ENDRIIN; HEPTACHLOR; IMIDACLOPRID; METHOXYCHLOR; POINT SOURCE AND NONPOINT SOURCE POLLUTION; TOXAPHENE.

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#### **Petrobras oil platform failure Brazil, offshore (March 15, 2001) Water Pollution**

Petrobras (or Petróleo Brasileiro S.A.) was founded in 1953 and operated as Brazil's state-owned oil exploration and production company. In 1997, outside investors were allowed to buy stock in the company, although slightly more than 50 percent is still owned by the Brazilian government. Headquartered in Rio de Janeiro, Petrobras produces and distributes more than 2 million barrels (84 million gallons [320 million L]) of oil and oil-related products every day from its own wells, refineries, and pipelines. It is one of the 500 largest companies in the world.

#### **BACKGROUND**

Well known for its technological skill in drilling and finding oil in deepwater settings where the seafloor is between 1,000 and 4,500 feet (300–1,500 m) below the surface, the company began operating the world's largest offshore oil production platform, *Petrobras Platform 36 (P-36)*, 80 miles (129.8 km) off the Brazilian coast in 2001. The platform was constructed in 1995 by Fincantieri, one of the oldest and largest oceangoing vessel building companies in Europe, at a cost of more than \$300 million. *Petrobras Platform 36 (P-36)* originally was designed as a semisubmersible drilling and exploration rig, equipped with pontoons and columns, which, when

flooded, allowed the rig to sink to a predetermined depth and drill a well. These types of rigs are usually attached to the ocean bottom with mooring chains. Others use a series of computer-controlled dynamic positioning propellers or thrusters mounted on each corner of the platform to keep the rig centered over the borehole. Readily available, usable under a variety of conditions, and inexpensive (compared to jack-up and other types of platforms), semisubmersible drilling rigs can operate in water depths ranging from 2,000 to 5,000 feet (609.6 to 1,524 m) and are able to be detached quickly and towed to the next location after a well is completed and placed into service.

Weighing more than 33,000 tons (30,000 metric tons), *P-36* was converted from a drilling platform to an oil production platform by a Canadian company hired by Petrobras. These platforms are very large structures, some having working surfaces of more than several thousand square feet, where all machinery and support facilities needed to produce oil are placed, including housing for workers, spare parts, pumps, and so forth. Platforms can either be attached to the seafloor with large cables or mooring lines or be floating structures, maintained in position by a series of computer-controlled impellers, or water-thrusting engines. Artificial islands, made of fill material dumped from a barge or pumped to a specific location, are even constructed over large oil fields to serve as production platforms. *P-36* was a floating platform that connected or manifolded numerous oil wells extending from the seafloor into a pipeline that connected to a land-based oil storage terminal in Brazil.

*P-36* was extracting oil from Late Cretaceous and Tertiary sandstones and carbonates deposited in the Roncador oil field of the Campos Basin. The first producing well in the Campos Basin was put online in 1977, and today there are almost 500 wells spread out across 40 known reservoirs. The Campos Basin produces more than 1 million barrels (42 million gallons, or 159 million L) of oil and 565 million cubic feet (16 million m<sup>3</sup>) of natural gas every day. Reserves have been estimated at more than 8.5 billion barrels of oil (357 billion gallons or 1,351 billion L). The basin covers an area of almost 12,000 square miles (31,000 km<sup>2</sup>) and was formed as sediments rich in organic matter washed into shallow surface water bodies present along the east coast of Brazil. As the climate became drier, large deposits of salt formed, effectively sealing the oil within the sandstones and carbonates. These host rocks were later fractured and broken, and the hydrocarbons migrated into the open, interconnected breaks and formed large reservoirs of oil and natural gas.

## ACCIDENT AND SPILL

By March 2001, *P-36* was floating 80 miles (130 km) off the coast and producing about 84,000 barrels (4.4 million gallons [16.6 million L]) of crude oil and 46 million cubic feet (1.3 million m<sup>3</sup>) of natural gas per day, about 5 percent of all the oil produced by Petrobras in Brazil. Early in the morning of March 15, three powerful explosions rocked one of the aft starboard (rear left) support columns of the *P-36* platform. Ten workers were killed outright, their bodies never recovered, and another later died of severe burns. The platform quickly developed a pronounced list or tilt, which allowed seawater to rush in and flood the fairlead boxes. These are devices inside the support column where cables are stored or spooled, and the leads are used either to guide or position rigging cables around a fixed object or to allow them to uncoil in such a manner as to be clear of obstructions. Once these boxes or storage containers filled with seawater, the platform's list increased to almost 20 percent. The 164 workers left alive after the explosions were evacuated, and Petrobras quickly began salvage efforts to try to save the platform.



Rescue teams work to prevent the oil company Petrobras's platform *P-36* from sinking in the Campos Basin offshore from Brazil, March 18, 2001. (AP Images)



Divers arrived and, over the next five days, pumped a mixture of nitrogen (more than 4,000 tons [3,628 metric tons]) and compressed air into the damaged column to force out the seawater and stabilize the platform, thus preventing the list from becoming worse. Unfortunately, the column had been extensively torn open in the explosion, and, when the weather changed on March 20 and strong winds and heavy seas began to buffet the structure, salvage attempts were abandoned. Within a few minutes after divers cleared the 40-story-tall platform, *P-36* quietly slipped below the surface and sank in 4,000 feet (1,200 m) of water. Onboard was an estimated 400,000 gallons (1.5 million L) of oil.

The oil being pumped from the Campos Basin was fairly “heavy” crude, with an American Petroleum Industry (API) specific gravity of between 19 and 22 degrees. Although the primary purpose of the *P-36* was to support oil extraction, and not storage, a large quantity was present on and underneath the rig in pipelines, manifolds, and transfer vessels. In addition, 1,600 gallons (6,000 L) of diesel fuel, used to run engines and pumps, and a smaller quantity of lubricating oils, also were present in some quantity on the rig.

As the rig sank and its tanks and pipes were crushed and imploded by the pressure of the sea, the oil began to float to the surface and formed a thin but extensive slick. Petrobras applied chemical dispersants and attempted to deploy booms around the slick, but large waves made them ineffective. Fortunately, these same rough seas mixed and dispersed the slick, and the oil eventually formed tar balls and mousse—an emulsified mixture of water in oil. Mousse can range in color from dark brown to nearly red or tan and typically has a thickened or puddinglike consistency. The slick never reached the shore. Blowout preventers on the *P-36* wellhead had been connected properly and had sealed off the wells feeding oil to the rig. This prevented the overwhelming disaster that would have occurred if the dozen or so production wells that were connected to *P-36* had started releasing oil into the ocean. Ecological damage was minimal because the slick was far from sensitive shoreline habitats and currents and waves had worked quickly to dissipate it.

### AFTERMATH OF THE SPILL

The *P-36* rig was insured for \$500 million, and the claim filed by Petrobras was settled before the end of 2001. At the time of the *P-36* disaster, Petrobras was in the middle of an extensive expansion program, aggressively developing its reserves and pioneering

drilling and extraction technologies in deeper water. Some labor union officials and environmental organizations have claimed that in an effort to keep expanding its operations, Petrobras was paying less attention to safety. They point out that almost 100 Petrobras workers were killed in industrial accidents in the three years prior to the *P-36* incident, and 19 months later in October 2004, a second Petrobras platform, *P-34*, narrowly escaped sinking when an electrical failure shut down several crucial pumps and almost resulted in its capsizing.

Behind this intense hydrocarbon exploration and development effort was the political commitment by Brazil's leaders to make the country energy independent by 2005. The groundwork for this commitment to energy independence was laid in the 1970s when Brazil's economy was severely affected by the Organization of Petroleum Exporting Countries (OPEC) oil embargo. Vowing not to let itself become so vulnerable again, Brazil embarked on a serious program, not only to increase its oil reserves, but to find a practical substitute for gasoline. Being the world's largest producer of sugar, ethanol (ethyl alcohol) was quickly identified as the alternate fuel of choice. Fermented from sugarcane residues and heavily subsidized by the government, ethanol today accounts for almost 20 percent of the transport fuel used in the country and has developed into a multimillion-dollar industry. Ethanol exports from Brazil, particularly to Japan, were expected to reach more than \$1.3 billion by 2010. Thanks to this 30-year commitment to energy independence, farmers in Brazil can squeeze out 6,000 gallons (22,800 L) of ethanol for every 2.5 acres (1 ha) of planted sugarcane, and improvements in technology and crop selection are ongoing.

In the United States, which still imports 60 percent of its oil and where transport fuel-related uses of ethanol are less than 10 percent, the theoretical ethanol production from an equivalent corn field is only 4,000 gallons (15,142 L). The Energy Policy Act of 2005, however, increases the amount of ethanol and other biofuels that must be mixed with gasoline to triple the current amount being used to 7.5 billion gallons (28.4 billion L) by 2012.

See also OFFSHORE OIL PRODUCTION; OIL SPILLS; PIPER ALPHA OIL SPILL; WATER POLLUTION.

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**phosphorus** There are several enigmatic substances, especially inorganics, that are beneficial in certain forms and harmful in others. Perhaps the most extreme of these enigmas is the inorganic substance phosphorus. It is a primary component of bones and teeth in the human body, as well as adenosine triphosphate (ATP), and a necessary component for energy use in all cells of all living things. Some estimates place the average amount of phosphorus in a human body at more than one pound (0.45 kg). Phosphorus is one of the main reasons that humans can produce enough food to sustain their enormous population on Earth through its role in fertilizers. Yet the same substance is a major component in incendiary devices (bombs) and many other weapons, from tracer bullets to detonators. It is also a deadly poison and the primary component in several deadly nerve gases such as Sarin. How can it serve such different purposes? Simply put, if the phosphorus compound dissolves in water or aqueous solutions, it can be deadly; if not, it is beneficial. Phosphorus has been identified in 77 of the first 1,430 U.S. Environmental Protection Agency (EPA)-designated Superfund sites (National Priorities List) in which it was tested. It ranks 19th of the 275 most dangerous pollutants on the 2007 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USE, AND PRODUCTION

Phosphorus was discovered in 1669, and phosphoric acid was discovered in 1770. It is the 11th most common element, making up approximately 0.12 percent of the Earth's crust. It is a nonmetal in the nitrogen family and occurs in white, red, and black varieties. In its pure form, white phosphorus is a colorless to white waxy solid with a garlic odor, but it is commonly yellow in its commercial form. When exposed to air, it is luminescent, though it was mistakenly

termed phosphorescent until 1974, when the glow was properly explained.

White phosphorus spontaneously ignites at approximately 104°F (40°C), making it highly unstable. It must be stored underwater, in many cases, to prevent accidents. As a result, it has limited uses. Military applications include tracer bullets, incendiary bombs and other devices, smoke screens, and detonators. Fluorophosphate is used to make nerve gas. Civilian and industrial applications include steel manufacture, in rodenticides including Bonide Blue Death Rat Killer and Rat-Nip, as well as in matches and fireworks in the past. The main use, however, is to produce phosphates and other compounds, which are used in everything from medicines to food additives and fertilizers and detergents, among many other uses.

Traditionally, the United States has been the highest consumer of phosphorus: more than 41.1 million tons (37.4 million metric tons) in 2002 and 42.5 million tons (38.6 million metric tons) in 2005. Domestic production was also the highest in the world through 2005, when it was 39.9 million tons (36.3 million metric tons), but it has fallen steadily to 29.9 million tons (27.2 million metric tons) in 2009. In 2006, China surpassed the United States as the largest phosphate rock producer. Florida and North Carolina produced more than 85 percent of the U.S. total, and the remainder was produced in Idaho and Utah. Imports of phosphate in 2005 were 2.9 million tons (2.6 million metric tons), which is about average over the past five years to 2009, 99 percent of it from Morocco. About 95 percent of the phosphate rock mined in the United States was used to manufacture phosphoric acid and superphosphoric acid, which were used as intermediates in the manufacture of granular and liquid ammonium phosphate fertilizers and animal feed supplements. Approximately 45 percent of the phosphoric acid was exported as granular phosphate fertilizer, merchant-grade phosphoric acid, and triple superphosphate fertilizer. The rest of the phosphate rock was used in the manufacture of elemental phosphorus.

### ENVIRONMENTAL RELEASE AND FATE

The fate of white phosphorus in the environment depends upon the conditions into which it is released. If released into water, elemental phosphorus quickly reacts to form several compounds. The rate of this degradation is primarily dependent upon the amount of dissolved oxygen, temperature, and pH of the water, and the removal half-life generally ranges from one hour to about 10 days. High values of the three factors promote breakdown reactions. The

reactions are also quicker in freshwater than salt water. The primary breakdown products are phosphorous pentoxide, phosphorous trioxide, orthophosphoric acid, phosphorous acid, and at times phosphine. Most of these products are much less toxic than phosphorus, except phosphine, which is a deadly toxin. The EPA has limited phosphine to 0.3 part per million (ppm) under the Safe Drinking Water Act. Even though white phosphorus is resistant to microbial degradation, its breakdown products are not and are further degraded. In anoxic conditions, phosphorus degrades very slowly, if at all, and settles into the bottom sediments. From there, it can be ingested by bottom feeders.

The mobility of white phosphorus in soil is low, but it depends upon availability of oxygen, size, depth of burial, and whether or not it is coated with another compound. Phosphorus can develop a surface oxide layer that protects it from further degradation. In this case, it can persist for many years. If it is buried deeply or is under anaerobic conditions, it may also be highly persistent. In most cases, however, phosphorus is oxidized in surface or shallow soils to phosphate compounds in a matter of weeks to months. The phosphates can then be leached into deeper soil horizons or be taken up by plants and animals.

Phosphorus is very toxic to most forms of wildlife. The first real case of ecological poisoning occurred in Placentia Bay, Newfoundland, where wastewater from a manufacturing plant in 1969 caused a huge fish kill. Subsequent studies showed that less than one part per billion (ppb) of phosphorus in water is toxic to most fish. It is also highly persistent in muscle tissue of fish, posing a health threat to consumers. A similar situation happened at the Pine Bluff Arsenal, Arkansas, where macroinvertebrates were killed. Perhaps the most famous ecological disaster occurred in Eagle River Flats, Alaska. As a result of artillery and munitions training, burned phosphorus was deposited from the smoke and fallout in a salt marsh. Migratory birds died off in the thousands after ingesting phosphorus in the sediment.

### HEALTH EFFECTS FROM EXPOSURE

There are many adverse health effects from exposure to phosphorus. Inhalation of white phosphorus results in cough and damage to the mouth in which wounds do not heal and there is a slow deterioration of the jaw and teeth coupled with intense pain. This condition is called phossy jaw. Even breathing smoke from phosphorus can damage the throat and lungs, and the smoke can irritate the eyes. Ingestion of white phosphorus in even small amounts (less than one tea-

spoon) can produce stomach cramps, vomiting, severe diarrhea with loss of blood, extreme fatigue, and damage to the stomach, intestines, liver, heart, and/or kidneys. It can also cause coma and ultimately death if the dose is higher than 0.00176–0.0035 ounce (50–100 milligrams). Being burned on the skin with white phosphorus can result in heart, liver, and kidney damage. Phosphorus is classified in group D, not classifiable as a human carcinogen, by the EPA.

### REGULATIONS ON HUMAN EXPOSURE

The EPA requires the reporting of any environmental release of white phosphorus of one pound (0.45 kg) or more to the National Response Center. The Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) restrict the amount of phosphorus in workplace air to 0.1 mg per cubic meter for an eight-hour-day, 40-hour workweek. NIOSH has set a designation of immediately dangerous to life and health (IDLH) for any exposure of 5 mg of phosphorus per cubic meter of workplace air.

See also INORGANIC POLLUTANTS; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; WAR AND POLLUTION.

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**phthalate** Although this very high-volume chemical generally has relatively low toxicity, phthalate was at the center of a great public health controversy. Phthalates are primarily used as plasticizers in plastics to make them soft and supple. A major use for some of them was in teething rings, pacifiers, and other infant devices. It was found, however, that the phthalate could separate and leak out of the plastic

under certain conditions, such as being chewed. As a result of the ensuing public outcry, it was banned from all infant devices in 1999. That, however, was not the end of trouble for phthalates. They are also commonly used in medical devices such as intravenous tubing and bags. Outright bans have not been enforced because the threat is not universally recognized. At present, precautions are taken with certain at-risk populations such as infants, hemophiliacs, and kidney disorder patients.

There are many types of phthalates. The most commonly used phthalates are DEHP (di-2-ethyl hexyl phthalate), DIDP (diisodecyl phthalate), DINP (diisononyl phthalate), DNOP (di-n-octylphthalate), BBP (butyl benzyl phthalate), DBP (di-n-butyl phthalate), BzBP (benzylbutyl phthalate), DAP (diallyl phthalate), and DEP (diethyl phthalate). In the first 1,613 hazardous waste sites that the U.S. Environmental Protection Agency (EPA) assigned to the National Priorities List (Superfund sites), 733 were found to contain DEHP, though not all may have been evaluated for them. DBP was found in 471 of the first 1,585 sites, and DEP was found in 248 of the first 1,397 sites. In terms of the 275 most dangerous pollutants on the 2007 CERCLA Priority List of Hazardous Substances, DBP ranks 52nd, DEHP ranks 76th, BBP ranks 195th, and bis-(2 methoxyethyl) phthalate ranks 194th.

### PROPERTIES, USES, AND PRODUCTION

Phthalates are synthesized organic compounds that do not occur in nature. They are generally clear, colorless to slightly yellow liquids that do not evaporate readily. Phthalates were first produced in the 1920s, and some 1 billion pounds (454 million kg) was produced in 2004. Production of dioctyl phthalates alone ranged from 309 to 285 million pounds (140–130 million kg) per year from 1990 to 1998. Imports of dioctyl phthalates were 18 million pounds (8.2 million kg) in 1985 and 6 million pounds (2.7 million kg) in 1986 and 1988. In 1998, 4 million pounds (1.8 million kg) was imported, and between 14 and 27 million pounds (6.4 and 12.3 million kg) per year was exported from 1994 to 1998. They are a very high-volume product. The larger-molecule phthalates are primarily used as plasticizers in all kinds of plastics for all kinds of applications, whereas the smaller-molecule varieties are used for a number of different applications. These include solvents in perfume, nail polish, adhesives, lubricants, soap, shampoo, hairspray, pill coatings, detergents, wood finish, pesticides, paint pigments, rocket fuel, and many others.

DEHP is the most common of the phthalates. About 95 percent of DEHP is used as plasticizer in

polyvinyl chloride (PVC) to produce flexible vinyl products. DEHP is also known commercially as BEHP, Dioctyl phthalate, Pittsburgh PX-138, Platinol AH, RC Plasticizer DOP, Reomol D79P, Sicol 150, Stafflex DOP, Truflex DOP, Vestinol AH, Vini-cizer 80, Palatinol AH, Hercoflex 260, Kodaflex DOP, Mollan O, Nuoplaz DOP, Octoil, Eviplast 80, Fleximel, Flexol DOP, Good-rite GP264, Hatcol DOP, Ergoplast FDO, DAF 68, and Bisoflex 81. DEHP was first developed in the United States in 1939, but commercial production did not peak until the mid-1980s. Domestic production was 251 million pounds (114,000 metric tons) in 1982 and 286 million pounds (130,000 metric tons) in 1986. By 1994, production had begun to decline to approximately 258 million pounds (117,500 metric tons).

More than 17 million pounds (7.8 million kg) of DBP, a small-molecule but dangerous phthalate, was produced in 1994. More than 10 million pounds (4 million kg) of pure DNOP was also produced in 1994; it was most commonly used in a compound of 20 percent strength as a plasticizer.

### ENVIRONMENTAL RELEASE AND FATE

Phthalates are largely released as point source pollutants as spills during production, transport, and storage/disposal or as a result of improper handling and disposal or incineration of plastic. There is not much information about interaction of phthalates with the environment. DEHP is probably the best studied, although there are some preliminary and site-specific studies on others that indicate a similar response. DEHP has a strong tendency to adsorb to soil and sediments and, therefore, tends not to leach into groundwater. It appears to biodegrade in soil under aerobic conditions after a period of acclimation. If released to water, DEHP biodegrades rapidly with a removal half-life of two to three weeks after a period of acclimation. If released to air, DEHP is carried long distances and may be removed by precipitation wash-out. DEHP can bioconcentrate in aquatic organisms at experimental factors ranging from 2 to 4.

According to EPA's Toxic Chemical Release Inventory of 1987–93, DEHP releases to land and water totaled more than 500,000 pounds (227,272 kg), about 95 percent of which was to land. The largest releases in the United States occurred in Wisconsin, Tennessee, Ohio, New Jersey, and New York.

### HEALTH EFFECTS FROM EXPOSURE

All of the phthalates have a similar series of adverse health effects from similarly high levels of exposure. At low levels, they have low toxicity, but extreme



levels may be fatal. Acute exposure to DEHP may potentially cause mild gastrointestinal disturbances, nausea, and vertigo. Chronic exposure has the potential to cause damage to liver, kidneys, lungs, endocrine and blood systems, thyroid and testes, as well as producing negative reproductive effects. The real danger of DEHP is that it leaches from medical plastic bags and hoses into intravenous fluid treatments and even blood. It is estimated that DEHP occurs in concentrations of nine to 13 parts per billion (ppb) in intravenous (IV) fluids and 14–120 parts per million (ppm) in stored blood. On the one hand, for most people who have short exposures, these concentrations do not present an immediate or serious health threat. On the other hand, some people are sensitive to DEHP and can have severe adverse reactions to exposure. In addition, the Department of Health and Human Services considers DEHP to be reasonably anticipated to be a human carcinogen, on the basis of sufficient evidence of carcinogenicity in experimental animals, in which it greatly increased the incidence of liver cancer. The EPA considers it a probable human carcinogen, although the International Agency for Research on Cancer downgraded DEHP to not classifiable as a human carcinogen in 2000. People who require prolonged or repeated medical treatment with plastic hoses and bags may have an additional risk of cancer.

Of the other phthalates, most are of low toxicity except under extreme exposure. DNOP can cause some liver damage or even be fatal at extreme concentrations or, under low to moderate concentrations, be mildly irritating to skin and eyes. If pregnant female laboratory animals are exposed to extreme concentrations, it has also been shown to cause reduced litter size, increased fetal malformations, and developmental effects. DEP has been shown to have virtually the same effects. At extreme concentrations, exposure to BBP causes reduced body weight, reproductive and developmental damage, and an increased incidence of mononuclear cell leukemias in laboratory animals. Under these same conditions, exposure to DAP increased the incidence of chronic liver disease, incidence of lymphoma in males and mononuclear cell leukemia in both genders, and damage to the forestomach in laboratory animals. DBP, under these conditions, can temporarily reduce male fertility, as well as causing skin and eye irritation.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies regulate worker and general exposure to phthalates as the result of these health risks. The EPA limits the amount of DEHP in drinking

water to six parts per billion (ppb) under the Safe Drinking Water Act. They further require the reporting of any environmental release of 100 pounds (45 kg) or more to the National Response Center. The Occupational Safety and Health Administration (OSHA) restricts the amount of DEHP in workplace air (PEL) to 5 mg per cubic meter for an eight-hour-day, 40-hour workweek. The OSHA short-term exposure limit (STEL) is 10 mg per cubic meter for no more than 15 minutes. The National Institute of Occupational Safety and Health (NIOSH) has set the same general exposure limit (REL) and short-term exposure limit (STEL) as OSHA and a designation of immediately dangerous to life and health (IDLH) for any exposure of 5,000 mg of DEHP per cubic meter of workplace air. NIOSH estimates that about 340,000 workers, including 106,900 women, were potentially exposed to DEHP in the early 1980s.

Regulations on the other phthalates are not as complete or as stringent as they are for DEHP. The EPA limits the amount of DBP in drinking water to 34 ppm but requires the reporting of any release of 10 pounds (4.5 kg) or more. NIOSH restricts the amount of DBP to 5 mg per cubic meter of workplace air for an eight-hour-day, 40-hour workweek. Exposure of workers to DEP is limited by both OSHA and NIOSH to 5 mg per cubic meter for an eight-hour-day, 40-hour workweek. As many as 239,000 workers may have been exposed to DEP. Although NIOSH estimates that 10,393 workers were exposed to DNOP in 1980, there are no regulations on human exposure.

*See also* ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**phytotoxicity** Compounds or substances that damage or injure a plant are called phytotoxic (*phyto*, from the Greek word for “plant”). Phytotoxicity most commonly results from the overuse or improper application of pesticides, herbicides, or fertilizers. Many industrial wastes and pollutants such as heavy metals, petroleum compounds, and organic chemicals, however, can also be phytotoxic. Even irrigation, unless proper techniques are followed, can cause natural salt levels to rise so high that plant growth cannot be sustained. Phytotox-

icity occurs with organic chemicals, such as pesticides or petroleum compounds, if the contaminant diffuses into the phloem (food-conducting tissue) or xylem (woody tissue) of the plant. Once there, the phytotoxin disrupts cell membranes, blocking nutrient uptake and slowing plant growth. Although inorganic compounds such as metals and salts are needed in trace amounts for normal plant growth, at excessive concentrations they are enzyme inhibitors, interfering with the plant's basic metabolic systems. Phytotoxicity can express itself in three ways:

1. Stunting or delayed plant maturation.  
This phytotoxic effect becomes apparent when plants are not growing at their typical rate or are not as developed or robust as they should be at certain points in their growing cycle. Excess lead and copper levels in soil can cause stunting in plants.
2. Morphological distortion.  
Another indication of phytotoxicity is identified when plants and their leaves, flowers, or fruits are misshapen or distorted. Exposure to high levels of atmospheric hydrocarbons, ozone, and sulfur oxides can bend or twist leaves on many types of plants.

### PHYTOTOXIC EFFECTS OF COMMON INDUSTRIAL POLLUTANTS

Contaminant	Effect
Arsenic	Wilting of new cycle leaves followed by retardation of root and top growth and leaf necrosis (death).
Cadmium	Reduces photosynthetic rates, interferes with root system development, and damages the ability of stems to transmit water or sap to leaves.
Chromium	Stunted growth, poorly developed roots, and leaf curling. May interfere with metabolism of C, N, P, and Fe, as well as certain plant enzymes.
Lead	Usually concentrated in root and related root structures. Affects mitochondrial respiration and photosynthesis.
Naphthalene	Reduction in new or young plant growth weights.
Nickel	Blocks nutrient absorption by roots and inhibits photosynthesis and transpiration. Also can induce chlorosis (yellowing of plant tissue) and foliar (leaf) necrosis.
PCBs	Reductions in plant growth caused by interference with transpiration (water uptake) mechanisms.
PCP	Reductions in plant growth caused by interference with transpiration (water uptake) mechanisms.
Toluene	Negatively affects seed germination and plant weight. Toxic effect appears to be acute because toluene is not accumulated in plants.
Uranium	Disrupts plant enzyme systems and may interfere with nucleic acid formation. The very low levels of radiation emitted by natural uranium absorbed by the plant do not play a significant role in phytotoxic effects.

## 3. Russetting or bronzing.

When the leaves or fruit of a plant have yellowed or turned reddish brown (russeted), or have dead spots on their tips or margins, or have dead areas between the veins, then phytotoxicity is the likely cause. Pesticides and herbicides, if overused or not properly applied, can cause these symptoms of phytotoxicity.

An examination of the leaf provides the best way to distinguish between phytotoxicity and disease, poor soil conditions, or other forms of natural plant distress. If the injured leaf tissue is sharply defined with little or no color gradation between dead areas and healthy areas, then phytotoxicity is the likely cause. If damaged areas appear across the leaf as patches or in sections, then other causes of injury (dehydration, disease) should be suspected. These symptoms of phytotoxicity, stunted growth, misshapen or twisted leaves, and fruit russetting or bronzing, are collectively called signs of distressed or stressed vegetation and are often used during hazardous waste site investigations to help delineate, or map out, the extent of contamination.

The most striking examples of phytotoxicity occur near mines. Debris and residues generated during extraction and processing of coal, copper, iron, gypsum, and other minerals can cause significant environmental damage.

See also ARSENIC; CADMIUM; CHROMIUM; LEAD; NAPHTHALENE; NICKEL; PCBs; PCP; PESTICIDES; TOLUENE.

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**Piper Alpha oil spill North Sea, United Kingdom (July 6, 1988) Water Pollution**

Of the 40 most costly insurance claims filed between 1970 and 2005, there were only two that were not related to a natural disaster such as an earthquake, flood, or hurricane: the 9/11 World Trade Center attacks and the *Piper Alpha* platform disaster. The 1988 explosion and fire on the *Piper Alpha* platform killed 167 people (including two rescue personnel) and cost more than \$3.3 billion. It also resulted in major changes to safety procedures and protocols being used by those companies drilling for oil and natural gas in the North Sea.

**BACKGROUND**

*Piper Alpha* was first placed into service on the North Sea as an oil platform in 1976. Later converted primarily to recover and process natural gas, the platform had a working surface that extended more than 100 feet (30.5 m) above the choppy and frigid ocean waters. It was divided into three sections: a drilling derrick on one side, a processing and refining area taking up the center part of the platform, and crew accommodations at the other end. The rig and production platform (added later) were operated by OPCAL, or Occidental Petroleum (Caledonia) Ltd. OPCAL was part of a larger company—the Occidental Petroleum Corporation. More commonly known as Oxy, the Occidental Petroleum Corporation is an international oil and gas exploration and production firm with business interests and facilities in the United States, Middle East, North Africa, and Latin America. Oxy is the fourth largest U.S. oil and gas company and is a wholly owned subsidiary of Occidental Chemical Corporation (OxyChem), one of the world's largest manufacturers of chlor-alkali and vinyl. Oxy also is the largest oil producer in Texas and the largest natural gas producer in California. Although strongly committed to operating its businesses in accordance with all environmental laws and regulations, Oxy currently has been named as a responsible party in more than 130 federal or state equivalent Superfund actions, largely as a result of prior or legacy operations.

Three other experienced oil companies joined OPCAL as business partners in financing the extraction of oil from the Alpha well field: Texaco Britain Ltd (23.5 percent share of both expenses and revenues), Union Texas Petroleum Ltd (20 percent share), and Thomson North Sea Ltd (20 percent share). OPCAL (36.5 percent share), however, was responsible for operating the *Piper Alpha* rig in a safe and environmentally responsible manner. Although the

exact date is uncertain, there is general agreement that by the end of 1976 *Piper Alpha* was on station in approximately 470 feet (143.3 m) of water in the Piper Field, 120 miles (193 km) northeast of Aberdeen, Scotland, and producing oil from a 12-square-mile (31-km<sup>2</sup>) reservoir 8,000 feet (2,438 m) below sea level. By 1988, 226 people living and working on the platform for weeks at a time were extracting natural gas and some oil from 24 producing wells.

*Piper Alpha* was a fixed platform, anchored to the seabed on each corner by massive columns that had been attached to the submarine bedrock by skirt piles. These are sleeves arranged in a circular pattern around the column or jacket through which a supporting column or pile is driven, eventually resting on the bedrock. The jacket then is connected to the piles and the platform is secured in place. The deck support frame is attached to the jacket and the four main areas or modules of the *Piper Alpha* platform assembled: Modules B and C were the main production or working modules and Module D was the generation and utilities module. Other modules, built higher up on the deck frame, included the Mud Module, Storage Module, and Gas Conservation Module. Crew quarters were at the north end of the platform some 120–175 feet (36.6–53.3 m) above the ocean surface. All of the modules were separated by firewalls, and the living areas were placed as far from hydrocarbon recovery and production areas as possible.

At its peak, *Piper Alpha* was producing oil at the rate of approximately 300,000 barrels (12.6 million gallons [47.9 million L]) per day, about 10 percent of the total amount of oil from British fields in the North Sea, with a value of more than \$5 million per day. OPCAL and its partners built a storage terminal on the Orkney Islands and connected it to the *Piper Alpha* platform via a 30-inch- (0.76-m-) diameter, 128-mile- (206-km-) long pipeline. By 1980, oil yields had started to decline, and OPCAL decided to focus more on the recovery of natural gas or methane, a major component of the dissolved gases that were present in the oil from this field. In addition, the recovered gas contained several different types of volatile hydrocarbon condensates: propane, butane, and pentane. These condensates have high vapor pressures and low flash points and, along with the methane, were being discharged into the *Piper Alpha* wells at an impressive natural pressure of approximately 3,400 pounds per square inch (23,442 kPa).

*Piper Alpha* collected gas from its 24 wells in two large-diameter riser pipes that extended up through the platform from the seafloor. Machinery on the platform condensed, or separated, the liquid pro-

pane, butane, and pentane, and then discharged the methane gas into separate 18-inch- (46-cm-) diameter pipelines that fed both another platform and a gas compressing station anchored 30 miles (48 km) to the northwest. The physical alterations that had to be made to the *Piper Alpha* platform to accommodate its new natural gas mission resulted in significant compromises to its safety systems: The natural gas compression system was installed adjacent to the platform's control room, the structural steel members of the platform were not fireproofed, and emergency shutoff valves on the gas riser pipes left large amounts of residual gas in the lines upstream of the valves, even after they were closed. These inherent design and system flaws might have been manageable if a strong safety culture existed on the platform. Several postdisaster studies, however, indicated that neither company management nor line workers took safety and accident prevention seriously.

Emergency evacuation drills were rarely held, and safety training for visitors, temporary subcontractors, and regular platform workers was not conducted with any regularity. The platform's sprinkler and deluge fire control systems were in need of repair and replacement, and the diesel-powered fire pumps usually were in manual control mode, in violation of platform safety procedures. These pumps could flood the platform with massive amounts of seawater in the event of a fire, but workers would set them on manual mode so divers would not be pulled into the intake manifolds if they started automatically. Maintenance and repair staff would either forget or elect not to restore the pump settings to automatic mode. Once the pump was set on manual, in an emergency a trained operator would have to go to the pump's control panels and turn them on to provide water to the deluge system.

Most importantly, the platform's permit to work (PTW) system procedure was often not followed and, in many cases, completely ignored. A PTW system is a formal written set of procedures intended to identify and manage safety risks associated with certain potentially highly hazardous activities. It describes how the work is to be performed and the precautions that must be followed in completing the task. It also informs those performing the work, as well as their supervisors, managers, and colleagues, that a high-hazard task is under way and that only adequately trained personnel should be involved in the work. Finally, the PTW requires that the work be audited or inspected during and after its completion. On an oil production platform such as *Piper Alpha*, PTWs would be issued for such activities as welding, opening pressurized lines, and entering confined spaces. *Piper Alpha*'s PTW system appar-





Smoke pours from the burning *Piper Alpha* oil platform in the North Sea off the coast of Scotland, July 8, 1988 (AP Images)

ently was only sporadically enforced. Required sign-offs before and after the work were seldom obtained, results of gas monitoring not documented, and job-site inspections not done.

### ACCIDENT AND SPILL

In 1988, *Piper Alpha* was the oldest of the 120 or so oil rigs and platforms being operated in the United Kingdom's North Sea territorial waters, and its age, inadequate design, and lack of safety culture led to disaster. On July 6, 1988, a maintenance crew started to repair a backup, or secondary, condensate pump connected to one of the platform's two main gas riser pipes. They disconnected a relief valve from the pump but were not able to finish the repair before the shift ended. Rather than allowing the work to be completed at the overtime rate, the supervisor directed that a blind flange be placed over the opening where the relief valve had been connected to the main gas riser pipe. A blind flange is a solid metal disk that is bolted onto the end of a pipe or fitting as a seal. The maintenance crew was in a hurry, and the pipe was not being used anyway, so they only loosely attached the blind flange to the

gas riser. The PTW permit, partially filled out, was dropped on a desk in the control room as the crew ended their workday. They did not indicate that the work was incomplete and that the required installation of the blind flange had not been performed. The maintenance crew, which had not been properly trained in safety procedures, also did not mention to the platform operator that the secondary compressor pump had not been repaired and was still out of service.

Just before 10:00 p.m., the primary condensate pump on one of the main gas risers failed, and the platform operator switched to the secondary pump—the one from which the relief valve had been removed. Gas and oil began to gush at incredible force from the partially installed blind flange and made a noise that several survivors described as the “screaming of a banshee.” The gas formed a large flammable cloud over the platform, found a source of ignition, and exploded. This explosion tore apart oil lines, and burning oil spilled into the sea. The fire continued to be fed by both residual gases present in internal lines of the platform and other platforms that sent their gas to *Piper Alpha*. Although operators on these other platforms could

see a problem on *Piper Alpha*, without instructions to shut down the flow of gas, they continued to feed methane to the burning rig. It was nearly one hour before platform operators shut down gas transfer operations to *Piper Alpha*.

Without an adequate deluge system and with the fire pumps inactivated (no one could get close enough to the controls to turn them on), the fire burned essentially out of control and began to weaken the structural steel of the platform. One estimate placed the rate of natural gas being burned in the fire as that being used by all of Great Britain. Workers fled to the crew modules, to await rescue. The intensity of the flames, however, hindered evacuation efforts. The flames and smoke were too intense to allow helicopter landings (the heat from the 300-foot- [91.4-m-] high flames could be felt one mile [1.6 km] away), and the rescue boat permanently assigned to the platform had to move out to sea in order to avoid catching fire.

The noise, smoke, lack of emergency evacuation training, and poor communication system resulted in general confusion among those gathered in the crew's quarters. As the fire approached that end of the platform, workers faced a terrible decision: either stay in the accommodations module and hope for rescue or jump more than 125 feet (38.1 m) through a burning pool of oil that had accumulated at the base of the platform and into the freezing waters of the North Sea. "Fly or fry" was the way one survivor phrased the choice.

Of those who jumped, many perished, but 62 were rescued, most with severe injuries and burns, by Royal Navy and other ships that had quickly assembled. Of the 165 people who died on the platform or in the water, many (81 in all) were killed by smoke inhalation while lying on the floor in the accommodations module with wet rags and towels over their nose and mouth.

Within three hours of the initial explosion, the billion-dollar *Piper Alpha* platform was lost, melted, and sinking with a roiling hiss into the North Sea, taking the dead and dying with it. The relatively minor amount of oil released into the ocean from the platform's burst lines did not create a significant ecological hazard. *Piper Alpha* was more than 100 miles (161 km) away from sensitive shoreline habitats, and the platform's below-water automatic shut-down valves had functioned well. Insurance reimbursed OPCAL for the destruction of the platform as well as for lost production. Approximately \$700,000 in compensation also was paid to each of the families of those killed or severely injured by the disaster.

## THE AFTERMATH

The loss of the *Piper Alpha* badly shook the confidence of both the oil industry and the British government about the safety of its North Sea hydrocarbon exploration and extraction operations. The inquiry convened after the disaster made several recommendations that, when finally implemented, fundamentally changed the approach to offshore platform design, management, and safety. A new government agency was formed: the Health & Safety Executive (H&SE). This agency's mission is specifically focused on developing and implementing programs and policies to minimize risks to those working on offshore platforms and drilling rigs. To accomplish this, the H&SE frequently inspects oil platforms, audits their operations and procedures, and aggressively investigates accidents and worker complaints.

As part of the overhaul of the regulatory system that governed platform operations, new goal-setting or performance-based rules were enacted. These new rules replaced highly specific or dogmatic directives with ones that allowed for greater flexibility and assigned more responsibility in the design of platform safety systems. For example, instead of requiring that a platform be made of a specified grade and thickness of steel, the new goal-setting regulations simply required that a platform had to be able to withstand a certain temperature for a given period without failing; the material it was made of was not important, so long as it could meet the performance standard. This approach allowed for much more creativity in the incorporation of safety systems into platform design.

The final major change to offshore safety was the requirement that any company operating in this arena had to have an effective and meaningful safety management system, or SMS. Such a system must set objective performance standards for platform operations and be able to demonstrate that the offshore installation is designed to operate in a safe manner with the major risks to workers minimized. As part of the SMS, quantitative risk assessments (QRAs) must be performed on all aspects of platform design and operation in order to collect structured, objective, numerical data. These data then can be applied to the measurement of risk in order to make clear comparisons of the effectiveness of safety methods. In other words, a QRA numerically demonstrates how probable a harmful event is and how severe a particular consequence would be as a result of using a certain safety measure.

The sad lessons of *Piper Alpha* have not been lost on those companies that drill and extract oil from under the sea, and this vital industry's safety record

has improved dramatically since the 1988 disaster. However, paraphrasing Lord William Douglas Cullen, the Scottish judge who oversaw the public inquiry into the *Piper Alpha* catastrophe, the fire and explosion were not an accident, but rather an abrogation of the responsibility of the platform's owners and operators to provide a safe working environment to those people who had entrusted their lives and health to them.

See also ENVIRONMENTAL REGULATIONS OVERVIEW; OFFSHORE OIL PRODUCTION; OIL SPILLS; WATER POLLUTION; WORLD TRADE CENTER DISASTER.

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**plastic trash in the oceans** Plastic trash can be seen virtually everywhere on every beach at any time. There are two reasons: People generate huge amounts of plastic trash and it is virtually indestructible. The production of plastic in the United States was roughly 3 million tons (2.7 million metric tons) in 1960 and 50 million tons (45.5 million metric tons) by 2000. A good proportion of that production is purely waste, and recycling programs are not widespread or adhered to enough to prevent it from being at least an eyesore, if not a hazard. Much of the plastic waste enters marine environments, where it is especially destructive. It is estimated that the navy, merchant vessels, and fishing vessels dump more than 135,000 tons (122,727 metric tons) of plastic trash directly into the ocean as waste. The National Academy of Science estimated that the commercial fishing industry loses or discards some 149,000 tons (135,455 metric tons) of fishing gear

on an annual basis. This gear, including ropes, nets, buoys, and traps, is largely plastic. The industry also dumps 26,000 tons (23,636 metric tons) of plastic packaging material annually. More than 7 million tons (6.4 million metric tons) of waste is also added from cargo and cruise ships per year. In addition, recreational vessels and the oil industry contribute significant amounts of waste depending upon the year. Plastic trash is a worldwide problem, as it is produced everywhere and found everywhere.

Plastic is nearly indestructible and, therefore, may pose a threat to the environment for hundreds of years. Under the right conditions, it is estimated that an ordinary plastic six-pack ring can persist for 450 years. With the abundance and durability of this material, which was certainly not designed to be environmentally friendly, plastic waste has become a hazard to many marine animals. It is estimated that as many as 30,000 fur seals die per year as a result of becoming tangled in discarded plastic fishing nets or choking on plastic cargo straps. Lobster and crab traps are entirely or partly constructed of plastic and are efficient at trapping their prey. The problem is that lost traps continue to trap prey even though no one empties them. It is estimated that in one year, some 25 percent of the 96,000 set off the west coast of Florida were lost as a result of storms or carelessness. Plastic bags and sheets suffocate whales, porpoises, and coral by covering or entangling them, and sea turtles die of eating them. Seabirds die after getting entangled in six-pack rings and fishing line, as do some marine mammals. Plastic trash is as great a danger to marine life as oil spills, toxic waste, and heavy metals.

To combat this grave danger, the Marine Plastic Pollution and Control Act of 1987 was signed into law and enforced by the U.S. Coast Guard in U.S. waters. The law prohibits the dumping of plastic debris from ships for any reason. Other waste may be dumped beyond a certain limit, and ports must provide waste facilities. Some companies have begun to use plastics that degrade when exposed to sunlight, but sunken biodegradable plastic lasts just as long as nonbiodegradable plastic. Considering the immense amount of plastic waste generated by beachgoers and beach/shore communities, it does not appear that this problem will be resolved anytime soon.

See also MARINE LITTER; OCEAN DUMPING.

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### point source and nonpoint source pollution

All pollutants are emitted to the environment, whether to air, water, or soil, either from point sources or from nonpoint sources. The basic difference between the two is that point source pollution has a single source or grouped sources that can be identified, whereas nonpoint source pollution is produced by numerous diffuse sources that may not be easily identified. Point source pollution typically occurs at much higher concentrations than nonpoint source pollution. The sources themselves are very different, and even the pollutants are generally different, though there can be significant overlap. It is the specific details of the individual cases of pollution that determine which of the two is the source.

### POINT SOURCE POLLUTION

Point source pollution can be devastating to the public health and environment in a specific area, but it is usually not extensive in area. Although the concentration of the pollutant is generally high, the total volume of the release is generally small compared with that of nonpoint sources. Point source pollution is most common in groundwater; it can be from Superfund sites, landfills, leaking underground storage tanks (USTs) from gas stations, houses or industry, broken pipelines, septic systems, industrial spills, military facilities, waste pits and lagoons, mines, and other sources, where all of the pollution has a single identifiable location. The type of pollution is relatively unique for several of these sources.

Fuel is the most common point source pollutant in groundwater, whether home heating oil, diesel, or gasoline, but it can also be from a nonpoint source. It most commonly leaks from USTs at gas stations and homes with oil heat. Other point source pollution in groundwater can be caused by industrial

chemicals. Common pollutants include tetrachloroethylene (PCE), which is mainly from dry cleaners; trichloroethylene (TCE), which is a solvent used in degreasing; and methyltert-butylether (MTBE), which was used in fuel, among many others.

Fuel may also be the most common point source pollutant in surface water. Oil spills from tanker accidents, oil well blowouts, and oil transfer spills are more common in marine waters, and raw sewage is probably more common in rivers. In the United States, raw sewage in rivers is less common today but was very common in the past. Animal waste from stockyards may be more common today but it is usually only a problem during storms and floods. Acid mine drainage (AMD) is common around many types of mines and is composed of sulfuric acid, which lowers the pH of the surface water body into which it empties. AMD dissolves the minerals out of the mine wastes, and, as a result, there is heavy metal contamination as well. Mines and mineral processing facilities can also cause pollution of surface waters through suspended particles of heavy metals and other pollutants in surface runoff. Gold processing can even produce cyanide as a point source pollutant.

Soil pollution from a point source is typically found where there is groundwater pollution from a point source because the liquid pollutant must leach through the soil to reach the groundwater, and some adheres to the soil particles or is trapped in the pore spaces. Soil pollution is also common at mines and provides the source of pollutants for the runoff to remove during storms and floods. Animal stockyards are point sources for soil pollution as well. These examples are linked to point source pollution of other media. Soil, however, may also contain point source pollution that does not affect or only marginally affects the other types. Prior to the Resource Conservation and Recovery Act (RCRA), landfills could have been buried directly into soil without any containment. Depending upon the waste and climate, the landfills may affect groundwater, as well. In many industries, waste metals were simply dumped behind or around the manufacturing facilities. Materials such as chromium, mercury, lead, nickel, and even radium were simply dumped into holes or even on the surface. Until such time as these wastes are physically removed, they remain at the sites indefinitely.

Point source pollution into the air is probably the most noticeable to the general public. Smokestacks belching out dark-colored smoke at incinerators, coal-fired power plants, oil refineries, steel and metal refineries, and any other stationary source are probably the most visible. These sources produce



## DEICING CHEMICALS AND THE ENVIRONMENT

The transportation of goods and the ability of people to move in a safe and efficient manner are essential to ensuring an adequate distribution of resources, capital, and intellectual assets, which are key components of every country's economy. The Romans built and maintained a complex system of roads to ensure rapid deployment of troops and easy import and export of goods to its population centers. The Inca developed a 14,000-mile- (22,500-km-) long sequence of trails and paths through the Andes Mountains that connected cities in Chile and Ecuador with their capital in Peru. The Chinese constructed the Gansu Corridor, part of a major transportation system called the Silk Road, a 740-mile (1,200-km) improved and, in places, paved, trail that connected the massive country's western borderlands and the Yellow River (Huang Ho) valley, the birthplace of Chinese civilization.

The United States developed an extensive interstate highway system during the late 1950s through the early 1990s. It was not, however, for the convenience of working commuters or for the speeding of tourists to vacation destinations but instead for national defense and interstate commerce. The main appropriations bill that established the National Highway Trust Fund through a federal tax on retail gaso-

line sales and began the era of interstate highway construction was called the National Interstate and Defense Highways Act of 1956. Originally envisioned as providing evacuation routes from major cities in the event of nuclear attack, interstate highways also were designed to allow for the movement of troops and materials in the event of invasion or widespread civil unrest. In fact, portions of Interstate 80, the main east-west highway connecting New York to San Francisco, has been designed in places to serve as emergency runways for the B-52, America's long-range bomber. Reportedly even today, late at night, sections of Interstate 80 are closed occasionally so that B-52s can practice "touch and go's" on the highway. The 47,000 miles (75,600 km) of the U.S. interstate highway system required 35 years to complete and cost more than \$420 billion.

But complicating the operation and maintenance of the interstate highway system is the weather. Route 80, as well as all the other roads and highways built in the northern three-quarters of the country, is occasionally covered with ice and snow. Snow can be removed physically, but ice tends to coat the roadways, and it is dangerously slippery and responsible for numerous serious accidents every year. To



Loading road salt in Columbus, Ohio, ca. 2007 (AP Images)

keep highways and roads open and safely passable, a variety of deicing agents are liberally applied to their surfaces, and each of these compounds has an associated environmental effect.

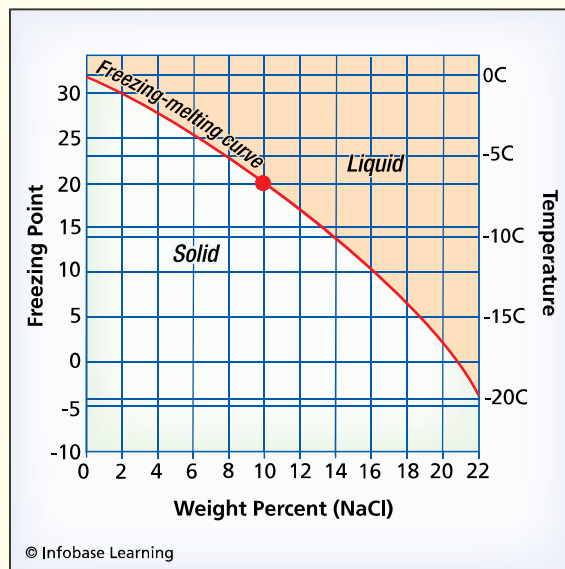
### ROCK SALT

Rock salt, or halite (NaCl), is the most commonly used deicing compound. It also is the most environmentally damaging. Rock salt is different from table salt in that after mining, the halite that is to become table salt is dissolved into a brine solution and then recrystallized as a fine white uniform mass. Supplements, such as iodine, are added to it before packaging for retail sale. Salt is essential for human health because it balances the flow of nutrients into and out of cells and helps regulate blood pressure and central nervous system functions. But human tolerances for this compound are fairly narrow. An excess of salt can cause hypertension (high blood pressure), edema (fluid retention), gastrointestinal ulcers, and cardiovascular disease. A lack of salt can result in dizziness, muscle cramps, and even fatal neurological damage.

Water that is salty (has a chloride concentration greater than 35,000 mg/L) is not potable and cannot be used for agricultural or other industrial or commercial purposes. Freshwater is defined as having a chloride concentration of less than 1,000 mg/L, but the U.S. Environmental Protection Agency sets a limit on chloride concentration in water to be used for drinking of 250 mg/L. One teaspoon of salt dissolved in 5.6 gallons (21.2 L) of water results in a chloride concentration of 280 mg/L.

Readily available and inexpensive (about \$50 per ton or three cents per pound), rock salt lowers the temperature at which water freezes, thus preventing the formation of ice. In pure water, ice forms at 32°F (0°C), but when salt or any compound that is soluble in water is added, the temperature at which water freezes drops. This is because the bonded oxygen and hydrogen atoms present in liquid water move more rapidly than those same paired atoms in ice. As heat is removed from the liquid water, the movement of the oxygen and hydrogen molecules slows, until, when the freezing point is reached, the motion is slow enough to allow the formation of solid ice. When salt is added to water, the salt and water molecules combine, and more heat must be removed to slow their movement, freeze (stop), and separate these larger salt and water molecules. This means that the temperature at which salty water freezes is lower than that of pure water.

A solution of 90 percent water and 10 percent salt (10 percent salt solution) freezes at approximately



Graph showing the temperatures of the freezing-melting curve for water as a function of concentration of salt (NaCl)

20°F (-6°C), and a 20 percent solution freezes at 2°F (-16°C). This means that, unless it is very cold, the addition of salt to a road's surface will melt or soften the ice and allow it to be scraped easily off by a plow. At very low temperatures, below approximately 15°F, the salt cannot penetrate into the ice structure, and very little or even no melting will take place. At those or lower temperatures, the use of abrasive (i.e., sand) to improve tire traction is a more effective ice management solution.

Salty water is electrically conductive because of the dissolved sodium and chloride ions; as a result, it hastens galvanic corrosion. This is a type of metal degradation or rust that occurs whenever two different types of metals, such as steel and aluminum, are in contact with an electrolyte such as salty water. The two metals act essentially as terminals on a battery, and the salt water acts as a wire between them. This causes rapid deterioration of the metal as low levels of electrical current flow from one through the other. This is the reason that cars and trucks in northern climates deteriorate more quickly than those in the South.

More than 15 million tons (13.6 metric tons) of salt is applied annually to roadways in the United States. This total includes the less aggressive but still environmentally damaging salts of magnesium chloride (MgCl<sub>2</sub>) and calcium chloride (CaCl<sub>2</sub>). On roads where salt is spread to control icing, environmental stud-

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ies show that soil, vegetation, surface water and groundwater, as well as such highway facilities as guard rails, bridges, and concrete, and vehicles can be adversely affected. The majority of soil and vegetation damage occurs within 50–100 feet (15–30 m) of the road and is greatest close to the pavement, but salty runoff from highways can contaminate underlying aquifers, as well as nearby streams and rivers. At Mirror Lake in the White Mountains of New Hampshire, one study found that chloride concentrations had increased 10-fold after the opening of a nearby highway (I-93). Salty water flows into the lake via a drainage channel that received highway runoff. The study predicts that by 2025 the concentration of sodium will triple and the concentration of chloride will increase eight times over preroad construction concentrations. Steps are being taken to reduce the use of salt on the highway and to divert surface water flows away from the lake.

The effect of salt on plants and animals has been well documented and generally results in a reduction of species diversity and higher mortality rates. Plants have to work much harder to remove water and nutrients from salty water. This leads to browning or stunted growth. Conifers are one of the most sensitive species, showing signs of damage at salt (chloride) concentrations as low as 30 mg/L. Uptake of salty water lowers the resistance of native plants to disease and predation and opens ecological avenues for less desirable invasive species such as cattails or reeds. In freshwater bodies, algae growth and health, the basis of most ecosystems' food web, can be disrupted by salt concentration increases in the range of 10–15 mg/L. Fish, especially trout, are affected at 250-mg/L ranges, with a 50 percent mortality rate reported at around 6,500 mg/L. Behavioral abnormalities have been reported in birds that ingest only a few grams of salt, as a result of their inability to distinguish the salt particles from seeds. Unlike carnivores, which metabolize much of the salt they need from meat, large herbivores such as moose and deer often have salt-deficient diets. They are attracted to roadsides, where they drink salty water or lick halite recrystallized on pavements or nearby structures. This increases road kill rates, as well as the damage to motor vehicles.

The outdoor storage of large piles of road salt also can result in soil and groundwater contamination. One such example happened in the small town of Hefley, British Columbia, in Canada (population 700). The town stored an abrasive-salt mixture used for servicing a 25-mile (40-km) stretch of four-lane highway in two outdoor piles. The town's water supply is taken

from a series of nearby wells. In 1993, the local water utility began to receive complaints that the drinking water tasted salty. The subsequent investigation quickly led to the conclusion that the salt storage site had contaminated the groundwater supplying water to town residents. New wells were drilled and the top eight feet (2.5 m) of contaminated sand and gravel underlying the piles was removed. This material, some 5,700 cubic yards (4,350 m<sup>3</sup>), was crushed, combined with salt, and stockpiled for future use in road maintenance activities. The costs of the drilling of five new production wells and installation of new piping, pumps, and so on, was approximately \$1.2 million. The highway authority then constructed a salt storage building, which cost about half of the cleanup at \$600,000. It would have been far less expensive to construct a proper storage facility than to remediate salt-contaminated soil and groundwater after they were polluted.

Today, most state and local highway and related regulatory agencies recognize the environmental threats posed by outdoor, unprotected storage of road salts. These materials are now placed inside specially constructed igloos that have impervious concrete floors and internal drainage systems or salt traps, designed to prevent water that may leak from or have contact with the salt from entering surface water or groundwater. In addition, new salt application procedures are being implemented to reduce the amount of salt being spread and minimize its potential environmental impact. These include presalting roads before major snowstorms; applying the salt in liquid form, which allows it to interact with the ice and snow already on the roadway more efficiently and at lower temperatures; and even using computer-controlled spreaders that can sense the amount of ice or snow on a roadway and apply only that amount of salt needed to help remove it.

## ABRASIVES

Sometimes used in combination with salt or as a stand-alone ice/snow management agent, sand as an abrasive is also often spread onto roadways to improve traction. Sand (SiO<sub>2</sub>) typically is the material most commonly used, but some communities that have access to large quantities of either free or very-low-cost industrial by-products have made use of ground-up slag, mining residues, wood chips, fly ash, or bottom ash from coal burning, and other relatively inert materials as traction control aides. This practice, however, has largely fallen out of favor because of concerns related to both accident liability and possible environmental impacts.

To be effective, sand usually must be mixed with some salt to prevent it from freezing and to help ensure a good bond with ice and snow that may already be on the roadway. Sand that is angular provides better traction than rounded or smooth sand grains. The optimal size for traction control sand is large and ranges from medium sand (0.012 inch [0.3 mm]) to fine gravel (0.38 inch [9.5 mm]). Smaller particles actually create slicker surfaces, and larger sizes may result in damage to vehicles.

Chemically, abrasives do not pose much of an environmental hazard. They do not degrade or interact to form hazardous or ecologically damaging compounds. They can, however, increase turbidity and change sedimentation patterns in surface water bodies. This can lead to adverse habitat impacts for aquatic vegetation and insects as light levels and stream or lake depths are reduced. This, in turn, can affect fish feeding and migratory relationships, as well as subsequent ecological interactions with higher-order species. Abrasives tend to accumulate in catch basins and drainage pipes and need to be removed periodically. During dry periods, they can cause dusty conditions that reduce visibility and degrade local air quality. Many of the control procedures being used to improve management of potential environmental effects of salt applications are also employed for abrasives, including more precise application, improved storage, and upgraded sediment control and water conveyance systems.

### LIQUID DEICERS

Another class of cold weather management materials are liquid deicers. These include agricultural by-products from sugar and grain (corn) distillation. Corn, beets, and many other agricultural products undergo a steeping process, whereby the material is immersed in a solution of warm water to help hydrate and separate it. In the case of corn, this is done to remove the husk or other noncommercial components. This water, which now contains dissolved carbohydrates and other plant ingredients, can be used in animal feed products or processed into road deicing compound. Liquid deicers are mixed or applied in combination with salt or sand. They work at lower temperatures than halite and adhere better to most road surfaces, so less has to be applied. Liquid deicers commonly are used as "antiicers," applied before frost, ice, or snow accumulates and has a chance to adhere to the road surface. The use of a liquid deicer allows snow and ice to be removed more readily with plows and scrapers. The first antiicing application usually is done before the first ice or snow of the season begins, and

the product is reapplied as needed after plowing to reduce ice or snow bonding.

In the environment, liquid deicers are more biodegradable than salt or abrasives. These materials, however, can contain high concentrations of soluble organic carbon, as well as growth nutrients such as nitrogen and phosphorus. Since they are liquids, these deicers can more easily enter the ecosystem and increase both carbon and nutrient loading on surface water bodies. This may result in waterway eutrophication, which has significant impacts on local ecosystems. High levels of nitrogen in the groundwater, in excess of 10 mg/L, can render the groundwater nonpotable and, if the nitrogen-rich water is ingested by infants or young children, cause methemoglobinemia. Most state transportation agencies now specify the use of low-carbon and low-nutrient-content liquid deicers for use on roadways and airport runways.

An alternative to both salts and agriculturally derived liquid deicers is a class of alternative deicing agents, of which the primary one is calcium magnesium acetate, or CMA. This is a biodegradable, noncorrosive compound made up of limestone mixed with acetic acid. Depending upon the concentration being used, CMA can be an effective antiicing agent down to temperatures close to -22°F (-30°C). Once in the environment, CMA breaks down to calcium and magnesium, as well as acetate. The acetate, an organic compound, is quickly degraded by microorganisms present in soil and water as a carbon source. CMA works more slowly than salts and liquid deicers and is much more expensive, costing almost 20 times as much as an equivalent amount of salt. As it gains more widespread use, especially for roadways in ecologically sensitive areas such as national parks, CMA may become more cost-competitive.

The need to keep highways and airports free of ice and snow must be balanced with the environmental and infrastructure effects associated with the use of salts, abrasives, liquid deicers, and other snow and ice management agents. Transportation authorities have the difficult task of selecting and using snow and ice control techniques that work and are cost-effective, while minimizing effects on surface water, groundwater, and air quality. As is the case with many other human-environment interactions such as pest management, the best approach may be one that combines a variety of methods that evolve as deicing products and application technologies improve.

*See also* AQUIFER; EUTROPHICATION; PHOSPHORUS; STREAMS.

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by Robert P. Blauvelt

particulate (fly ash), polycyclic aromatic hydrocarbons (PAHs), benzene, NO<sub>x</sub>, SO<sub>x</sub>, CO, CO<sub>2</sub>, and many other vaporized pollutants such as mercury. There are numerous other point sources of air pollution that are not so obvious. These are chemical plants and other manufacturing plants that use organic chemicals. The pollutants are in vapor form from the evaporation of volatile organic compounds (VOCs) and are probably even more abundant in the atmosphere. Some air pollution can be in the form of particulate, blown by the wind off mine spoils, piles at manufacturing facilities, trains, and dump trucks in the form of dust. These can include heavy metals, asbestos, lime, phosphates and other fertilizers, sulfur and sulfides, and numerous other powders. There are also natural point sources of pollution such as volcanoes and forest fires.

### NONPOINT SOURCE POLLUTION

Nonpoint source pollution is generally not as ecologically devastating as point source pollution in the short term, but it affects far more people and is more likely to cause major and lasting damage to the environment and public health. It is in generally low concentrations that are unlikely to be a public health hazard individually or even collectively in most cases. The problem is that the sheer volume of pollutants released by many nonpoint sources is immense. A National Academy of Sciences report found that in North American coastal waters "the thousands of tiny releases, carried by streams and storm drains to the sea, are estimated to equal an Exxon Valdez spill—10.9 million gallons of petroleum—every eight months." These pollutants can cause major and perhaps irreparable damage to the environment on a regional to global scale. It is the nonpoint source pollution that is responsible for the most pressing of our environmental problems.

According to a study by the National Oceanic and Atmospheric Administration, nonpoint source pollution affects "the beauty and health of coastal lands and waters. If the physical environmental well being of these areas is diminished, people will naturally find it less appealing to visit the coast." This same study finds that U.S. coastal and marine waters support 28 million jobs and contribute more than \$30 billion to the domestic economy through domestic fishing alone.

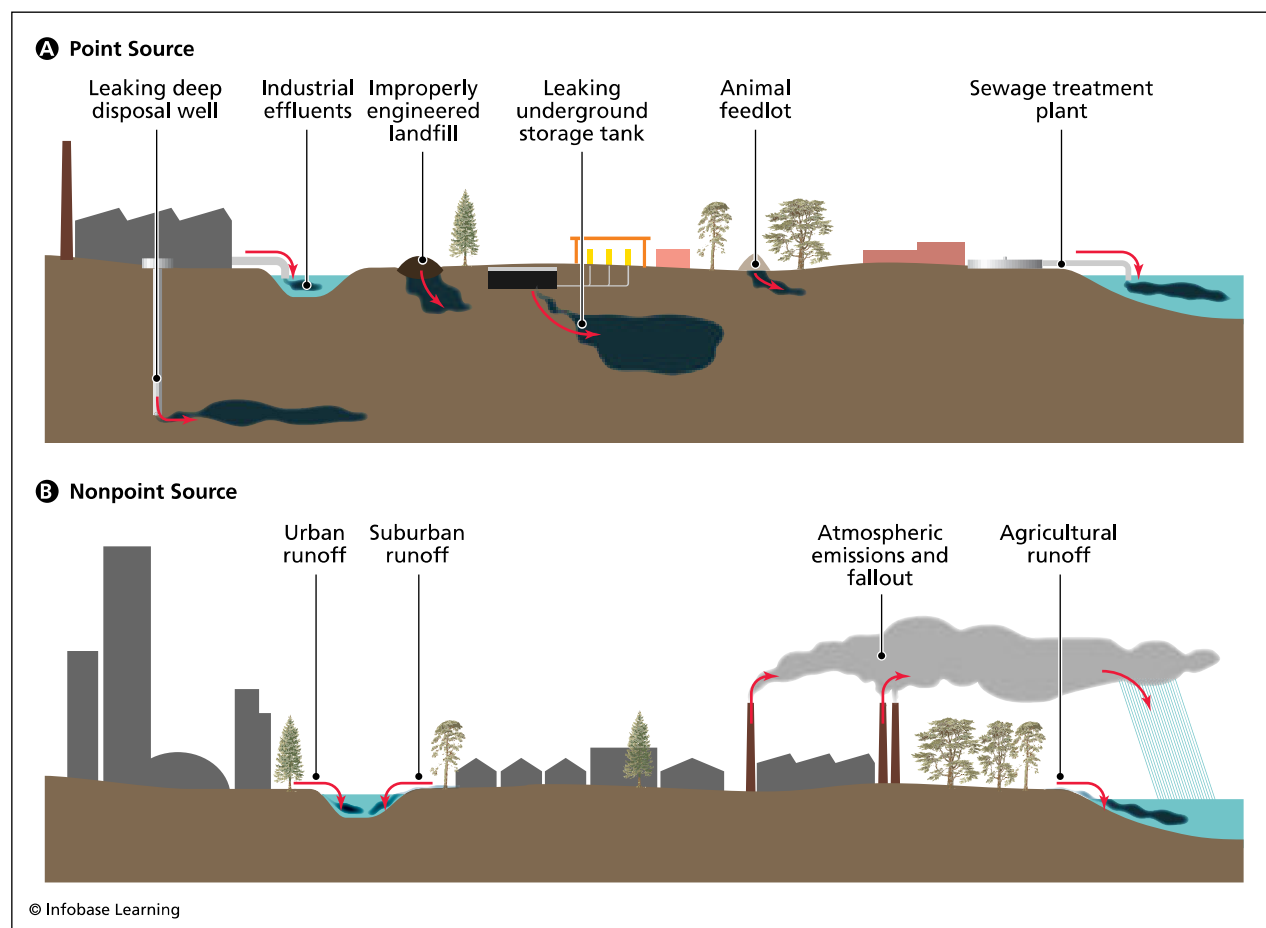
Nonpoint source pollution has many small sources to which most humans contribute. Nonpoint source air pollution is primarily from automobile exhaust. It emits benzene, NO<sub>x</sub>, SO<sub>x</sub>, CO<sub>2</sub>, CO, particulate, and partially burned hydrocarbons, all of which are the main components of urban smog. All other engines produce the same products. There are many other nonpoint combustion sources including home and industrial furnaces, fireplaces, grills, and open fires. The main pollutants from these sources are PAHs, CO<sub>2</sub>, CO, and particulate, though they may vary depending upon composition. The CO<sub>2</sub> from nonpoint sources is the main culprit in global warming and the greenhouse effect. The NO<sub>x</sub> and SO<sub>x</sub> produce acid precipitation, which originates primarily in nonpoint sources. The other main classes of pollutants are vapors from volatile chemicals. Every time gasoline or other fuel is exposed to the air, a small part evaporates. This same process occurs with drying oil paint and finish, glues and other adhesives, solvents, sprays, photocopying, and many other everyday items. These VOCs react with the NO<sub>x</sub> in the atmosphere to produce tropospheric ozone, which is very damaging to plants.

Surface water is also greatly affected by pollutants from nonpoint sources. Urban and agricultural runoff is the main vehicle for pollution. In urban and suburban areas, there are numerous chemicals on the surface that are swept into surface water

bodies during storms and floods. Fallout from the rampant air pollution coats most surfaces. Lawns and gardens are sprayed with pesticides and fertilizers. Areas with septic systems risk overflow of raw sewage, especially during spring thaw and other wet periods. Roads contain numerous compounds ranging from road salt and other deicing compounds to spilled oil, gasoline, and antifreeze from the motor vehicles passing over. There are chemicals on houses, sidewalks, parking lots, and businesses, in addition to all of the litter that is common to these areas, all of which are washed in the runoff into sewers and, untreated, into surface water bodies. A study conducted by two researchers on Long Island, New York, found that “bacteria and other contaminants enter the South Shore bays, the Peconic bays, the Long Island Sound and other surface water in the runoff from heavy rains, when drains divert huge amounts of water from roads and parking lots.” All of this input produces eutrophication of these bodies. The washout of NO<sub>x</sub> and SO<sub>x</sub> also produces acid precipitation that can cause

a public health threat, degrade urban infrastructure, and destroy the ecology of sensitive lakes and ponds.

Agricultural nonpoint sources produce most large-scale damage to the environment. Fields are doused with fertilizer before the seeds are planted and sprayed with pesticides afterward. Both of these are used in excess to ensure maximal yield of the plants. During storms, the fertilizer is dissolved or carried as particles in surface runoff and deposited in lakes and rivers. This process causes eutrophication of the lakes; the rivers carry the excess nutrients to the oceans. If the marine input area is restricted as in a bay, gulf, sound, or sea, eutrophication also takes place, producing a dead zone. The water of these dead zones is oxygen deficient to the point where they cannot support any life beyond jellyfish. All fish and invertebrates either escape or die, destroying the productivity of these areas. Destruction of the food output from such a vast source as the ocean may have dire consequences for the human race.



**Block diagrams showing some common sources of pollution in which there is a single point source (A) that can be readily identified and there are diffuse nonpoint sources (B) that cannot be readily identified**

Pesticides are equally overused and damaging to human health and the environment. Although pesticides have saved millions of human lives by controlling disease-carrying insects and crop-destroying insects, they also produce collateral damage. In the 1960s and 1970s, tests showed that there was so much pesticide in human breast milk worldwide that it was dangerous to babies. In response, many persistent pesticides were banned in favor of more selective and potent, shorter-acting types. The problem with milk subsided, but there is now a crisis in honeybee populations in which pesticides are strongly suspected. The crisis is called colony collapse disorder (CCD); in it whole hives simply perish all at once. It is especially prevalent in North America, where nearly one-third of the already greatly diminished population of honeybees disappeared in 2007. The problem is that the vast majority of the pollination of flowers is done by honeybees. Without them our supply of all fruits and nuts and most vegetables is in jeopardy.

These agricultural and home use pesticides and fertilizers also leach into the groundwater system. Residues are found in well water throughout the United States. The problem is especially acute in coastal areas, where all drinking water must be taken from the shallow aquifer because the deeper water is saline. Any fertilizer or pesticide applied to the surface quickly leaches through the sandy soil that characterizes these areas and enters the groundwater system. This reliance on this commonly contaminated shallow groundwater in these areas may be the reason for the elevated incidence of cancer.

There are also natural nonpoint sources of pollution. Soils and rocks in an area can contain elevated levels of dangerous inorganic pollutants. Arsenic is the most widespread and perhaps the most common of these dangerous pollutants. The worst case of natural arsenic poisoning is in Bangladesh, where tens of millions of people suffer its effects. In some cases, it is the interaction of anthropogenic pollutants with the natural sources that causes the problems. Some agricultural fertilizer can strip naturally occurring mercury from clay deposits and release it into the groundwater system. Other less dangerous chemicals such as sulfur are widespread in groundwater and degrade the quality. Sulfur also lowers the pH of the water, with the potential to dissolve copper and lead from the plumbing system, further degrading the water quality.

See also AGRICULTURE AND POLLUTION; AQUIFER; ARSENIC; BANGLADESH, ARSENIC IN SOIL AND GROUNDWATER; CARBON DIOXIDE; CARBON MONOXIDE; DEAD ZONE; EUTROPHICATION; LANDFILL;

LEACHATE; LEAD; MERCURY; MINING AND POLLUTION; NOX; OIL SPILLS; OZONE; PAH; PARTICULATE; PESTICIDES; SALTWATER INCURSION; SOIL POLLUTION; SULFUR DIOXIDE; VOLATILE ORGANIC COMPOUND; WATER POLLUTION; WELLS.

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**Pollution Abatement Services Oswego, New York (1977–present)** *SoilandGroundwater Pollution* By the 1960s, the water quality in Lake Ontario had deteriorated to the point where it was on the verge of ceasing to be a viable ecosystem. Phosphate-rich sewage, primarily from household detergents, poured into the lake, causing enormous algae blooms that drastically lowered the water's oxygen content and killed thousands of fish. Runoff from farms that contained high concentrations of agricultural chemicals such as pesticides, herbicides,

and fertilizers combined with untreated industrial wastewater to add a toxic component to the already degraded water. By the early 1970s, conditions had worsened to the dangerous level, and both the American and Canadian governments were forced to act. Sewage treatment plants were upgraded, and phosphates were banned from laundry detergents. An intensive education and outreach program to local farmers was successful in reducing the amounts of agricultural chemicals used and in improving the quality of surface water runoff into the lake. Finally, industrial sources of lake pollution began to receive scrutiny. One of the first to merit close attention was Pollution Abatement Services, a 15-acre (6-ha) site in Oswego, New York.

### BACKGROUND

Oswego is a small town of about 18,000 inhabitants on the shore of Lake Ontario. This part of western New York holds the distinction of receiving some of the heaviest snowfalls in the lower 48 states. During winter, the wind picks up moisture as it blows across the lake and dumps it on Oswego, Syracuse, and other nearby cities. Often as much as 20 feet (6.1 m) of snow per season falls in this part of the country. Around 1902, a local resident tried to capitalize on the water and freezing temperatures. He installed a concrete dam along the northwestern corner of a 15-acre (6-ha) tract about two miles (3.2 km) east of downtown Oswego and the Oswego Canal and only 1,800 feet (550 m) south of the lake itself. This small parcel was surrounded on its east, north, and west sides by White Creek and Wine Creek, as well as wetlands. These streams flow northward from upland farms and pass through the area on the way to Lake Ontario. Damming up the streams allowed the winter ice to be harvested and stored for sale in the nearby growing town of Oswego or even barged by canal to Syracuse. The business, however, foundered as electricity and refrigerators became more commonplace, and Oswego County eventually took ownership of the property because of unpaid taxes.

### POLLUTION OF THE SITE

Undeveloped for many years, the site began to be used as a landfill during the 1950s, receiving rubble and demolition debris as the post-World War II construction boom swept across western New York. Looking toward more sustainable regional development, Oswego County and the Port of Oswego Authority (Port Authority) turned over the site to a group of local businessmen for the construction and operation of a high-temperature liquid chemical

waste incinerator. This operation became known as Pollution Abatement Services, or PAS.

PAS began operating in late 1969 and, at its peak of operation, employed some two dozen local residents. The facility received liquid wastes in tanker trucks and drums, classified their contents, and incinerated the material for a fee. Operating under permits from both Oswego County and the state of New York, the business prospered. The chemical industry was very active in this area, and PAS was providing a much-needed waste management service. Throughout the 1970s, as environmental regulations became stricter and competition from other waste disposal sites increased, residents began to complain about the stacks of drums and strange smells emanating from the site. A series of events that began in 1973 attracted the attention of regulatory agencies to PAS's increasingly shoddy operations.

PAS was not a large site. To increase the liquid storage capacity, operators constructed three lagoons, or retention basins, on the property. They also installed numerous aboveground and underground storage tanks. Even with this increased capacity, PAS accepted liquid waste material faster than it could safely incinerate or even store it. The lagoons regularly overflowed, with chemical wastes entering a drainage ditch directly down the center of the site and discharging into White Creek. A few hundred yards downstream, White Creek combines with Wine Creek and this combined flow empties into Lake Ontario.

The area around PAS was fairly rural during the facility's operational life. Some private residences were to the north of the site, but land use was primarily undeveloped woodland. A few dozen homes are clustered about a half-mile (0.8 km) north of PAS, on the shore of Lake Ontario in an area known as Smith's Beach. A union hall was to the east, and a radio station had its offices on the west. The Oswego County landfill was to the south of the PAS site. The local environmental and public health impacts from PAS were not insignificant, but the real threat posed by the site was in the area where White and Wine Creeks enter Lake Ontario. It is about one mile (1.6 km) from the drinking water intakes for the city of Oswego. Chemicals from the PAS site that overflowed into surface streams made their way to Lake Ontario and possibly into Oswego's water system. In addition, the White and Wine Creek stream system, although biologically stressed by impacts from PAS and other contaminant sources, supports numerous bird and aquatic species. The streams also are spawning grounds for a number of fish species and, near Lake Ontario, are used for recreational fishing.



Between 1973 and 1977, PAS was cited for numerous violations of its permits and for illegal discharges into the air and surface water. In 1977, the site was abandoned, and its employees and owners simply stopped showing up for work. They left on-site more than a million gallons (3.8 million L) of oil and mixed chlorinated and nonchlorinated hydrocarbons and more than 15,000 leaking and deteriorating drums full of chemical wastes. Faced with a large and expensive cleanup, the New York Department of Environmental Conservation (DEC) and the U.S. Environmental Protection Agency (EPA) turned to the Clean Water Act for funding to clean up the site. Although these federal funds were originally intended to build municipal sewage treatment plants, the situation at Oswego was considered so dire that the rules were stretched to provide some initial financial support.

### THE CLEANUP

A dike was quickly constructed around one of the lagoons to prevent it from overflowing. Next, the dangerous liquids were removed from the lagoons, the contaminated sludge scraped out, and the open hole backfilled with clean soil. More than 80,000 gallons (302,400 L) of liquid waste had to be drained from the storage tanks, and then these tanks had to be cleaned and torn down. More than 15,000 drums were still present on the site, many of them requiring overpacking, a procedure in which a rusting or damaged 55-gallon (208-L) drum is placed carefully inside an 85-gallon (321.3-L) drum so it can be shipped safely to an off-site disposal facility. By 1980, both EPA and NYSDEC realized that the work needed to stabilize and secure PAS from a fire, spill, or other sort of catastrophic event far exceeded the available funds, and work slowly came to a halt.

With Clean Water Act funding almost exhausted, the EPA nominated PAS for inclusion on the newly formed National Priorities List. In 1981, the site was placed on the list, with a final ranking of number 8, and federal Superfund monies now became available to address the remaining site stabilization issues. By 1984, the majority of the wastes had been removed from the PAS property, but soil and groundwater quality had not yet been investigated, and the impacts of past releases on local ecology including White and Wine Creek stream sediments, were still unknown. In addition, severely contaminated soil and black oily leachate were present near the former tanks and could be a source of continuing surface water and groundwater contamination.

Prior to the selection of a remedial solution, a feasibility study (FS) is conducted. The EPA's stated

goal for the FS is to identify and evaluate remedial alternatives and select one that is the "lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare, or the environment."

During site stabilization activities, a wide variety of contaminants were identified, including waste acids and alkalis, polychlorinated biphenyl (PCB)-contaminated solids and liquids, halogenated organics, organic resins, and heavy metal-laden wastewater. These compounds are toxic and/or carcinogenic and represent a significant risk to worker safety, public health, and the local ecology. To evaluate the extent of soil and groundwater contamination, samples were taken across the 15-acre (6-ha) site. Findings suggested that soil contamination was significant, often approaching saturation values, but was widespread and nonuniform. This type of distribution pattern indicated that there had been multiple contaminant sources on the property.

The groundwater was in better condition. Soft shale and limestone bedrock in the area had been scraped out by glacial action during the last ice age and pulverized into a fine clay or a mix of densely compacted sand, silt, and clay and deposited around Oswego, including at the PAS site. Underlying a thin layer of demolition debris that had been laid down across the site when it was a landfill, there is a 10-foot- (3.1-m-) thick layer of a glacially derived dense, low-permeability ( $2.5 \times 10^{-5}$  inch/s [ $5.5 \times 10^{-5}$  cm/s]) lodgment till. This till acts as an effective hydraulic barrier to the downward migration of contaminants into the underlying moderately fractured sandstone bedrock.

Although groundwater within the till is contaminated, especially in areas where most of the waste was stored such as the aboveground tanks and lagoons, this shallow water is not used regionally as a source of potable water. The risk that this shallow impacted groundwater poses is that it discharges as surface seeps and springs into the channels of White and Wine Creeks, which flow into Lake Ontario and discharge near the water intake for Oswego. In fact, groundwater contamination was found in only one monitoring well in the upper part of the fractured sandstone bedrock, and that was linked to poor drilling practices. It was determined that the seal around the monitoring well casing was not installed properly and that shallow groundwater was trickling down the length of the well and entering the underlying bedrock aquifer. Once that well was removed and the borehole sealed, further contamination in the fractured sandstone was not detected. The presence of the lodgment till also

allowed the development and implementation of an effective remedy to control migration of shallow groundwater off the PAS property and into White and Wine Creeks.

A slurry wall, also called a diaphragm wall, or cut-off wall, is a subsurface barrier consisting of vertically excavated trenches filled with a clay slurry, a soupy mixture of water and fine sediment. The slurry is usually a combination of bentonite (a type of clay that expands when wet), Portland cement, coal ash, and water. It is poured into the trench to prevent the walls from collapsing during excavation, but it also greatly reduces or even eliminates the flow of groundwater through it. As the trench is deepened and connected to a less permeable subsurface layer or even bedrock, if it has the right characteristics, the excavated soil is mixed with more bentonite and returned to the trench, where it hardens. Essentially, it creates an underground dam. As added protection, a layer of plastic can be draped across the downgradient side of the trench to slow groundwater flow further and prevent the migration of vapors that may be emanating from the contaminated groundwater. Slurry walls can be installed at depths as great as 100 feet (30 m) and are generally two to four feet (0.6–1.2 m) thick.

At the PAS site, a slurry wall was constructed around the most contaminated areas to the base of the lodgment till. Collection sumps were installed inside the wall, where groundwater is periodically recovered by using a vacuum hose, literally sucking it into a tanker truck. This recovered groundwater is then driven to an authorized disposal facility for processing and eventual discharge. Approximately 400,000 gallons (1.51 million L) per year of recovered groundwater is managed in this way, and this process, coupled with an extensive groundwater monitoring program, is likely to continue for the foreseeable future.

### THE AFTERMATH

While this work was ongoing, the EPA and NYSDEC reviewed PAS's business records and identified almost 100 companies that paid PAS to accept and process their wastes. These 100 companies, called "potentially responsible parties," were notified that they must reimburse the EPA for the cleanup activities it had undertaken at PAS. If they refused, the EPA would have filed a cost recovery action in federal court under its CERCLA "joint and several liability" authority. After tough negotiations, they agreed, and most of the funding for the cleanup was shifted from Superfund to the group of potentially responsible parties.

Further studies by EPA, NYSDEC, and the potentially responsible parties concluded that concentrations of contaminants in the soil decreased with depth, with almost all of the volatile organic compounds and PCBs present within the upper 10 feet (3.1 m). Remedial engineers concluded that this contamination was best addressed by removing the most highly contaminated soil and capping the remainder of the site with a clay layer in order to reduce the likelihood of human exposure and to help isolate it from the environment. A supplemental study concluded that the PAS site was not the source of pesticides in the surface water of Wine Creek and is not presently a source of PCB contamination in the sediments in the adjacent wetlands or the creeks. PAS was a likely source of PCB contamination before remedial activities had been completed. This same study identified two other likely PCB sources in the vicinity of PAS.

The PCBs found in White and Wine Creek sediments were determined not to pose a serious enough risk to local flora and fauna to justify the habitat destruction associated with their excavation and removal. Groundwater in the bedrock was not contaminated, but, as a precaution, the Oswego municipal water supply system was extended to the area, and nearby users were given the opportunity to connect to it. Many declined, preferring to continue to use private wells. A review of the effectiveness of the remedial action at PAS, conducted every five years by EPA, concluded that the cleanup activities implemented and ongoing at the site were fully protective of human health and the environment. The EPA further found that, under current conditions, potential or actual human exposures are under control.

Thanks to the cleanup of PAS and other sites like it, as well as the more regionally implemented water quality initiatives such as the banning of phosphate detergents and the upgrading of sewage treatment plants, the majority of Lake Ontario is now a thriving sports fishery and an important recreational center for both Canadians and Americans. Its pristine beaches are popular tourist destinations, and introduced coho and chinook salmon are flourishing. While in places lake sediments still contain troubling levels of mercury, PCBs, and other industrial contaminants and invasive species such as the zebra mussel still pose problems, progress has been made and Lake Ontario once again stands out as one of the most outstanding natural resources in North America.

*See also* IN SITU GROUNDWATER REMEDIATION; LANDFILL; LEACHATE; MERCURY; PCB; PESTICIDES; SOIL POLLUTION; SUPERFUND SITES.

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**Poza Rica disaster Poza Rica, Mexico (November 24, 1950) Air Pollution**

Hydrogen sulfide ( $\text{H}_2\text{S}$ ), also called swamp gas or sewer gas, is a dangerous asphyxiant. Colorless, highly flammable, and explosive, hydrogen sulfide is heavier than air and often accumulates in enclosed, low-lying, or poorly ventilated areas. Although it has a very disagreeable smell of rotten eggs at concentrations as low as 0.5 part per billion (ppb) warning of its presence, it also acts as an olfactory deadening agent. As exposure duration increases, the hydrogen sulfide numbs or paralyzes the sense of smell, usually within a few minutes, leading the exposed individual to the false conclusion that the gas has dissipated. Rather, as is most often the case in industrial accidents, the  $\text{H}_2\text{S}$  gradually displaces the air and causes the deaths of workers and rescuers alike.

Once inhaled, hydrogen sulfide decreases the oxygen-carrying capacity of blood. The toxic effects are similar to those of hydrogen cyanide: The central nervous system slows as the lack of oxygen shuts down cellular respiration. Loss of consciousness occurs, and, without prompt medical treatment, death quickly follows. Low concentrations (<300 parts per million [ppm]) of hydrogen sulfide do not cause an immediate toxic response, but fatigue, loss of appetite, and headaches can result from long periods of low-level exposure. These symptoms diminish

within weeks after exposure ceases. Concentrations of 700–800 ppm are usually fatal within five minutes. At 1,000+ ppm, the majority of exposed individuals collapse immediately, after inhaling just one breath. Typical, naturally occurring  $\text{H}_2\text{S}$  concentrations in air range from 0.0001 ppm to 0.0002 ppm. The U.S. Environmental Protection Agency (EPA) has set a safe exposure level for hydrogen sulfide at 0.0014 ppm.

$\text{H}_2\text{S}$  can be released directly into the air from volcanoes and hot springs through the hydrolysis of sulfide-containing minerals such as pyrite ( $\text{FeS}_2$ ). In fact, about 90 percent of the hydrogen sulfide in the atmosphere is attributable to natural sources. It can also be produced by sulfate-reducing bacteria in stagnant-water, oxygen-poor settings, such as swamps or bogs.

The most important industrial sources of hydrogen sulfide are petroleum and natural gas extraction and refining. Certain types of textile production and pulp, paper, and chemical manufacturing, as well as municipal waste disposal, also produce hydrogen sulfide gas. It can be mixed or dissolved in both oil and natural gas, and concentrations range from a few parts per million to as much as 30 percent. Besides being a health hazard and an air pollutant, hydrogen sulfide causes corrosion and metal fatigue. As a weak acid,  $\text{H}_2\text{S}$  in the water or moisture of oil or natural gas enhances the absorption of hydrogen by steel. As the  $\text{H}_2$  penetrates the metal vessels and pipes of the refinery, the steel becomes brittle and loses its flexibility and strength. Eventually, it blisters, cracks, or simply breaks apart. In some cases, iron sulfides form and plug pipes and foul valves. Refineries deal with this problem by removing the  $\text{H}_2\text{S}$  from the hydrocarbon fuel and converting it to elemental sulfur. The hydrogen is burned along with other waste gases in a flare, while the sulfur is collected and often distributed commercially. Recently, some refineries have been experimenting with ways to collect the excess hydrogen and sell it as an alternative fuel source.

**BACKGROUND**

On Mexico's Gulf Coast, 20 miles (32.2 km) west of Tuxpan and 140 miles (225.3 km) northeast of Mexico City, the small town of Poza Rica (1950 population of 22,000) hosts a thriving oil and gas refining industry. Built on the floodplain of the Rio Cazones, Poza Rica is surrounded by hills rising about 330 feet (100.6 km) above the floor of the valley. Its climate is subtropical, with temperatures rarely dropping below 60°F (15.6°C). Most of the houses were

constructed of split bamboo, with large windows and doors to ensure maximal airflow. Many rested on platforms a few feet off the ground to allow as much air exchange as possible.

The refineries and associated sulfur recovery plants in 1950s Poza Rica were operated by Petroleos Mexicanos (Pemex), the government-run oil company. They were built to exploit the extensive deposits of oil and natural gas found in this part of Mexico. In November 1950, as production activities were being expanded, a new sulfur recovery plant was opened to remove hydrogen sulfide from the natural gas being processed at a nearby refinery. This gas contained about 3 percent (or 30,000 ppm) hydrogen sulfide. The sulfur recovery plant was divided into two units, with each unit able to process 60,000,000 cubic feet (1,699,011 m<sup>3</sup>) per day of natural gas. The final step in the process, when the concentrated hydrogen sulfide gas (16 percent or 160,000 ppm) was to be sent to a reactor to recover the sulfur, had not been constructed. Instead, the H<sub>2</sub>S was diverted to a tower, where it was mixed with low-sulfur methane and ignited in a flare that would reach heights of up to 30 feet (9.1 m).

### THE INDUSTRIAL ACCIDENT

Operational problems plagued the gas flare from the beginning. Amine solution, used to help remove the hydrogen sulfide from the natural gas, periodically overflowed and extinguished the pilot light of the flare or clogged its methane gas supply lines. Flow rates were reduced to 40,000,000 cubic feet (1,132,674 m<sup>3</sup>) per day, and this seemed to work for a while, but pressure on production staff to increase plant output was intense. At 2:00 A.M. on November 24, 1950, the facility's operator succumbed to this pressure and ordered flow rates to be increased to the maximal output of 60,000,000 cubic feet (1,699,011 m<sup>3</sup>) per day. For about 90 minutes, the process seemed to be working fine, but at 3:30 A.M., the strip chart recorders began to show that gas flow to the flare was erratic.

At 4:40 A.M., the shift supervisor implemented emergency shutdown procedures, but by then gas had begun to infiltrate the village. Later investigations found that the amine scrubber solution had overflowed and extinguished the flare's pilot light. For 20 minutes, between 4:50 A.M. and 5:10 A.M., 800,000 cubic feet (23,305 m<sup>3</sup>) of gas containing



Flare system at Pemex oil field in Poza Rica, Veracruz, Mexico, burning excess hydrogen and other waste gases © Sergio Dorantes/CORBIS



high concentrations of hydrogen sulfide escaped from the inoperative flare vent. At the time, a late fall temperature inversion in Poza Rica had produced a rare cool evening, with air temperatures in the low 60s°F (ca. 15°C) and a thin mist filling the valley. This inversion also reduced atmospheric mixing and forced the hydrogen sulfide gas to move laterally with the developing morning breeze, where it settled over a nearby residential neighborhood. Exposure concentrations were subsequently calculated at 1,000–2,000 ppm H<sub>2</sub>S.

In one home, only 400 feet (121.9 m) from the sulfur recovery unit, a father, awakened by the characteristic “rotten egg” smell of H<sub>2</sub>S, managed to snatch his infant daughter from her crib and stumble down the street before collapsing. Although he and the four-month-old baby survived, his wife and three other children died that night in their sleep. Townspeople formed makeshift rescue squads, dragging apparently lifeless residents from their homes and taking them by cab or truck to the hospital. Racing to the facility, the plant superintendent saw the bodies of employees and residents lying either dead or unconscious in the street. In all, 22 people perished from hydrogen sulfide exposure, and 320 were hospitalized. More than 50 percent of the pets and domestic livestock in the neighborhood were also killed. A mass funeral service was held a few days later for the victims, and the sulfur recovery plant was put back online.

### THE AFTERMATH

Today, Poza Rica is still the center of Mexico’s oil and gas industry. It is also trying to define itself both as a tourist destination and as a broad-based commercial and transportation center. The majority of its 500,000 residents probably do not notice the small black or gray boxes that contain H<sub>2</sub>S detectors that have been mounted on poles around the town in case there is another disaster.

See also AIR POLLUTION; TEMPERATURE INVERSION.

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**Prestige oil spill Galicia, Spain (November 13–19, 2002) Water Pollution** Spain is one of the most decentralized countries in Europe, containing 17 autonomous communities and two autonomous cities, which are subdivided into 50 provinces. Each of these autonomous areas has a wide degree of freedom to manage its own internal political and social programs such as health care, education, and security. Galicia, on the Iberian Peninsula along the west coast of Spain, is one of these autonomous areas. Bounded by Cape Fisterra, Galicia is the westernmost point of continental Europe, and its rugged coastline is known by mariners around the world as the Costa del Morte, or coast of death. The jagged cliffs that reach to the edge of the sea and beyond combined with fierce shoreward winds and strong currents have resulted in an average of three shipwrecks per year for the last 100 years.

### BACKGROUND

In addition to its dangerous maritime reputation, the coastline of Galicia is well known as one of the most scenic areas in Europe. Tourism is an important component of the region’s economy, and people travel from all over Europe to enjoy the lush green hills and valleys and rocky, isolated coves and bays on the coast. These same coves and bays provide important wintering habitat for seabirds from throughout the North Atlantic including gannets, guillemots, cormorants, puffins, and gulls. Galicia’s offshore waters are well oxygenated and nutrient rich and support an abundant variety of fish, shellfish, whales, dolphins, and porpoises. The Galician fishing fleet, composed mainly of small family-owned and operated vessels, is the largest in Europe, and many local residents make a living by gathering and selling shellfish.



After a structural failure, the oil tanker *Prestige* leaves a trail of oil near Muxia, Spain, November 13, 2002 (AP Images)

Galicia also is on one of the world's oldest and most important shipping lanes. Supertankers full of oil and other types of merchant vessels sailing from the Persian Gulf, India, and China make their way northward along the west coast of Africa and sail directly past Galicia on their way to ports in mainland Europe. Similarly, southbound ships skirting the coastline of Europe make their way past Galicia loaded with North Sea oil or goods from Western Europe as they sail westward toward the Americas. It was this type of voyage that the *Prestige* had been making uneventfully for most of its 26-year life, until early November 2002.

Launched in 1976, the tanker *Prestige* carried a crew of 27, was about 800 feet (243.8 m) long, and had a capacity of almost 23 million gallons (85,000 tons [77,000 metric tons]) of oil. It was an aging single-hull vessel that had undergone major repairs in a Chinese shipyard in 1991, having a number of cracks repaired in the hull. The tanker was loaded with heavy fuel oil (No. 6 or Bunker C) in the Latvian port of Riga and was bound for Singapore, around the Cape of Good Hope at the southern tip of Africa, after a brief stopover in Gibraltar. The *Prestige* was under the command of a Greek captain

with a mostly Filipino crew. At the time of the incident, the tanker was owned by a Liberian company, but on charter to a Russian oil business headquartered in Switzerland. The oil was the property of an English corporation, and the *Prestige* was registered in the Bahamas.

### THE OIL SPILL

While steaming south in either Portuguese or Spanish waters on November 13, 2002, the starboard side of the *Prestige* struck a partially submerged object. One crewman thought it might have been a derelict cargo container. Regardless of what the object was, it ripped a 150-foot- (45.7-m-) long gash through the hull of the ship, which began listing and leaking oil almost immediately. The captain radioed for assistance and turned toward the Spanish coast. Fearing that the *Prestige* would break apart and release its entire cargo onto the beaches of Galicia, Spanish coastal authorities ordered the vessel to turn around and head northwest, back to open ocean.

The captain changed course as ordered and steered toward France, but once again the *Prestige* was denied safe haven and ordered back to sea. Becoming desper-

ate and fearing for the lives of his crew, the captain turned toward Portugal, but the Portuguese navy was ordered to intercept the vessel and keep it away from that country's coastline. Now under tow by as many as five oceangoing tugs, the hull was becoming unstable, a condition not helped by the constant course changes and the deteriorating weather.

The captain requested that the crew be taken off the ship while he remained onboard with two volunteer crewmen to help with salvage operations. He pleaded with French, Spanish, and Portuguese shipping authorities to allow the *Prestige* to dock and off-load its cargo while there was still time. Concerned that a major catastrophe would occur if the ship were allowed into harbor, each country refused. With 20-foot (6.1-m) waves crashing over the damaged vessel, fighting winds of 50 miles (80.5 km) per hour, and still leaking oil, the *Prestige* was rapidly towed out to sea as far from the European mainland as possible. Finally, early in the morning of November 19, a 40-foot (12.2-m) section of the starboard hull peeled off, and, shortly after 8:00 A.M., the ship split in half. Later studies indicate that the hull failure may have occurred along one of the repair welds. The stern section quickly sank, while the bow floated for a few hours and eventually slipped beneath the surface in the early afternoon.

The *Prestige* sank in 12,000 feet (3.7 km) of water about 130 miles (208 km) off the coast of Galicia, releasing an estimated 18 million gallons (68 million L) of heavy oil. During the frantic, wandering search for a harbor and sinking, the *Prestige* created a slick 200 miles (322 km) long and five miles (8.1 km) wide that the winds and ocean currents moved quickly toward the Spanish, Portuguese, and French coastlines.

Since the 1970s, five of the 11 major oil spills in Europe have affected the Costa del Morte, but even for this much environmentally abused area, the *Prestige* spill was damaging. The oil went ashore in three distinct episodes. The first occurred on November 16, even before the *Prestige* sank, and the quantity of oil and its widespread distribution quickly overwhelmed initial cleanup efforts on the beaches. The second and largest slick arrived on November 20, the day after the *Prestige* sank, and the third "black wave," as the local residents called it, arrived on December 19, one month to the day after the *Prestige*'s sinking.

### THE CLEANUP

Although beaches in France and Portugal also were covered by oil, Galicia bore the brunt of the damage. Health authorities closed more than 1,000 miles

(1,609 km) of shoreline along both the northern and western coastlines of Spain. Intensive shoreline cleanup and ecological restoration attempts continued well into summer 2003, with thousands of volunteers, military personnel, and paid professionals collecting almost 110,000 tons (100,000 metric tons) of oil-contaminated materials from the Spanish shoreline.

The *Prestige* took almost 3.3 million gallons (12.5 million L) with it to the bottom of the ocean, and early Spanish claims that the heavy oil would congeal and not pose an ecological threat were quickly dismissed as the tanker continued to leak oil at an estimated rate of 30,000 gallons (113,562 L) per day. Temporary repairs by a French submarine a few months after the sinking slowed the leak rate to less than 200 gallons (757 L) per day. Finally, in summer 2004, a sophisticated remotely operated deep-sea robot sealed the cracks in the sunken stern and reportedly pumped most of the remaining oil into special aluminum canisters that were floated to the surface. Cleanup was not declared complete until December 2004.

### THE AFTERMATH

No fatalities were reported during the salvage and recovery efforts, but an estimated 15,000 birds died, and some nongovernmental agencies put the total number killed much higher at more than 100,000. The fishing and shellfish industry, on which some 80 communities along the Galician coastline depended, was destroyed, losing a combined \$70 million. It took more than two years to recover to prespill levels, but given the large amount of oil released, some experts have predicted that marine life could be impacted by the *Prestige* spill for as long as 10 years. This is because the hydrocarbons contained in the oil are capable of poisoning plankton, fish eggs, and crustaceans and may cause cancer in fish and other marine species.

Similarly, tourism dropped dramatically as beachgoers and bird-watchers sought less polluted places to spend their almost \$30 million vacation dollars. The captain of the *Prestige* was arrested and charged with hindering salvage attempts and creating a release to the environment but was not prosecuted. He was later sued, along with the owner and operators of the *Prestige*, for \$60 million of cleanup costs and for compensation to local fishermen. Some estimates of *Prestige*-related cleanup and compensation costs put the figure as high as \$2.8 billion, only about \$300 million of which was covered by insurance or civil liability compensation funding. The rest was paid by Spanish taxpayers.



Oil with chemical characteristics similar to that carried by the *Prestige* still washes up periodically on the Galician coastline, and the controversy over the *Prestige* was rekindled when a 2006 study by a group of Spanish researchers concluded that not all the oil had been removed from the wreck. Using an analysis of fresh, undegraded oil found floating near where the *Prestige* went down, as well as remote sensing techniques, they concluded that as much as 6.8 million gallons (26 million L) of oil could still be present within the sealed hull of the stern. They further concluded that bacteria are slowly eating through the hull and that a major release of oil is inevitable. Although the Spanish government and the contractor that performed the work discounted these findings, they continue to monitor the wreck.

See also *AEGEAN SEA OIL SPILL*; *CONTINENTAL SHELF*; *OIL SPILLS*; *WATER POLLUTION*.

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**Price's Pit Pleasantville, New Jersey (1981–2011)** *Soil and Water Pollution* In 1968, the 26-acre (10.4-ha) sand and gravel quarry owned by Charles Price closed. The quarry stretched across the boundaries of Egg Harbor Township and the town of Pleasantville, New Jersey, about five miles (8 km) east of Atlantic City. It had operated for only two years and its sand and gravel resources had been quickly exhausted. When local residents began to use the pit as an informal garbage dump, Mr. Price seized the opportunity to increase the earnings from the property. In 1970, he applied for and received permission from the recently formed New Jersey Department of Environmental Protection (NJDEP) to operate a sanitary landfill, which eventually became known as Price's Pit.

#### POLLUTION OF THE SOIL

Shortly after opening as a landfill for household trash and construction debris, Price's Pit began to accept chemical wastes for disposal. This was done in spite of the specific restriction on the landfill's operating certificate prohibiting the receipt of "Chemicals (Liquid or Solid)." It was not until 1972 that Price's Pit operators officially requested permission from NJDEP to accept chemical waste. The NJDEP cautiously approved this request with the condition that "no liquid or soluble industrial wastes, petrochemicals, waste oils, sewage sludge, or septic tank wastes shall be received for disposal at the site." This list is so comprehensive that it virtually excludes all types of chemical or industrial wastes. By the time this permit modification was issued, Price's Pit had accepted an estimated 9 million gallons (34 million L) of chemical waste for disposal. These wastes were haphazardly dumped on the ground, often poured directly from tanker trucks onto the quarry floor with no attempt at treatment. In other cases, drums of dangerous chemicals were tossed onto the ground and then covered with trash. There are even rumors of late-night dumping activities and abandonment of entire tanker trucks in the pit because the contents were too dangerous to unload.

After an NJDEP inspection in November 1972, Price's Pit operators apparently stopped accepting chemical waste. The pit continued operating as a "sanitary" landfill until 1976, when waste disposal operations ceased. The site was covered with a few inches of sand, the gate across the access road was locked, and the operators left behind one of the largest repositories of buried chemical wastes in the United States.

When it rained or snowed, precipitation infiltrated the thin layer of sand covering the top of Price's Pit and percolated through the waste, rusting or degrading the containers and liberating their contents. Once mobilized, the mix of dissolved contaminants began to move eastward, carried along by the flow of groundwater. The stage was set for a true environmental disaster because about 90 percent of nearby Atlantic City's drinking water is taken from groundwater sources.

The Kirkwood-Cohansey Aquifer, a clean, well-sorted sand that extends under most of the coastal plain of southern New Jersey, including Price's Pit, is Atlantic City's main source of drinking water. Atlantic City pumps approximately 10–15 million gallons (38–57 million L) per day from the aquifer to meet the needs of its citizens and the casino atriums and reflecting pools. Of the 10 wells that make up Atlantic City's public well field, four are between the city



and Price's Pit. As the contaminants migrated away from the pit, a plume formed.

A plume is an underground distribution of contaminated groundwater created when contaminant spreads laterally in the same direction of groundwater flow. The site of original contamination, or the source of the plume, has the highest concentration of contaminant, which decreases as it moves away from the source. As the Price's Pit plume expanded, it put at risk almost half of the drinking water supply for 40,000 people. In addition, 35 private homes along the northeast border of the pit relied on groundwater from shallow wells as their only source of potable water. Many of these wells withdrew water that intersected the contaminant plume and residents noted drastic changes in their water quality shortly after the pit began accepting chemical wastes. Trees began dying and local residents reported that their skin burned after taking a shower.

This process of dissolution and migration of contaminants by infiltrating precipitation is called leaching. It happens at landfills, burial pits, or anywhere that wastes are exposed to precipitation and infiltration. The amount and rate of leaching are determined by a series of complex processes that are dependent on a variety of factors, including the type of waste, local climate, and site hydrogeology. Five of these processes are directly related to the makeup of the soil: porosity, permeability, cation exchange capacity, pH, and organic carbon content. At Price's Pit, the soil is porous and permeable and has a low cation exchange capacity and low organic carbon content. All these factors contributed to the quick generation and migration of chemically contaminated leachate. It was only through some truly remarkable action by the U.S. Environmental Protection Agency (EPA) and NJDEP that a major environmental crisis was averted.

### REMEDIATION OF THE SITE

The movement of contaminants toward the Atlantic City well field, which was a little more than a half-mile (0.8 km) east of Price's Pit, was discovered when people living close to the landfill began to complain about their well water. The Atlantic County Health Department (ACHD) collected some samples, expecting to advise the homeowners to have their septic systems repaired or change water softeners. Instead, they found drinking water with organic solvents and heavy metals at concentrations in the hundreds of parts per million. Realizing that they were on the brink of a major public health crisis, the ACHD notified EPA and NJDEP and asked for help.

Acting quickly, both regulatory agencies implemented a series of short-term remedial actions. The threatened Atlantic City wells were either shut down, redrilled deeper, or fitted with water treatment systems. Bottled water was provided to local residents until the city mains could be extended to the affected areas and the homes connected to them. Price's Pit was identified as the likely source of the contamination, and, in October 1981, it was placed on the National Priorities List as a Superfund site, so that funding could be made available for further action. The EPA, NJDEP, and Atlantic County eventually reached an agreement with 50 companies that had sent waste to this permitted and licensed facility to pay for the majority of the \$17-million cleanup.

As hydrogeologic conditions were determined at the site, EPA and NJDEP designed a long-term remedial solution. This plan included the installation of an 80-foot- (24.4-m-) deep slurry or containment wall that encircled the waste disposal area and controlled the lateral migration of contaminants. A series of groundwater extraction wells were installed east of the landfill and screened in the upper and lower parts of the aquifer. These wells are withdrawing water at the rate of approximately 200,000 gallons per day (756,000 L) and control the migration of the contaminant plume from the landfill. For 30 years, recovered groundwater has been treated through a treatment plant and returned to the landfill. The effectiveness of this groundwater pump-and-treat system is evaluated by regular monitoring of homeowner and sentinel monitoring wells. Eventually, the landfill will be capped with a combination of plastic sheets and clay to reduce the amount of surface infiltration. On-site treatment includes pH adjustment by addition of lime, air stripping to remove volatile organic compounds (VOCs), off-gas treatment with a dehumidifier and vapor-phase carbon adsorption, and final polishing with a sand and granular activated carbon filter. However, the effluent still contains high concentrations of heavy metals and is piped to the Atlantic County sewage plant for further treatment, prior to final discharge into the environment.

*See also* AQUIFER; COASTAL PLAIN DEPOSITS; INORGANIC POLLUTANTS; KIRKWOOD-COHANSEY AQUIFER; LANDFILL; LEACHATE; ORGANIC POLLUTANTS; SUPERFUND SITES; VOLATILE ORGANIC COMPOUND; WELLS.

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**primary air pollutants** Those pollutants that enter the atmosphere directly from a smokestack, tailpipe, chimney, evaporation, or the like are termed primary pollutants because they are health

risks in their unaltered state. They are largely from transportation sources (46 percent); fuel combustion in a stationary source such as power plants, incinerators, and refineries (29 percent); industrial processes such as manufacturing, smelting, and mills (16 percent); miscellaneous sources such as volcanoes, forest fires, ocean waves (salt spray), continental dust, pollen and spores, and the like (7 percent); and solid waste disposal (2 percent). Of these primary pollutants, the most abundant in the atmosphere is carbon monoxide (CO), which constitutes about 48 percent of the total air pollutant weight followed by sulfur oxides (16 percent), nitrogen oxides (16 percent), volatile organic compounds (VOCs) (15 percent), and particulate material (5 percent). These numbers vary by location and by season. Essentially every place on Earth contains some sort of primary air pollutant; the hazardous areas are those where the concentrations are high. Human response to primary air pollutants ranges from respiratory discomfort and watery eyes to death, either quickly or after long-term exposure. The London “Killer Fog” in the United Kingdom in 1952 killed thousands of people outright, in contrast to exposure to atmospheric asbestos or benzene, which are carcinogenic and can induce lung cancer over time. Nearly 200 million tons (181.8 million metric tons) of criteria air pollutants were emitted in the United States in 1997.

# R

**radiation** There are numerous forms of radiation that people are exposed to on a daily basis. Some are dangerous, whereas others are not, and still others may or may not be. There are three major sources of radiation: cosmic, or extraterrestrial; from earth materials; and from assembled equipment and devices. Cosmic, or extraterrestrial, radiation includes solar radiation and cosmic rays. It is a mixture of many different types of radiation with varying intensity and health implications. Radiation from earth materials is the result of the decay of radioactive isotopes of elements in minerals and other materials that is present everywhere on Earth. Equipment can produce a number of different types of radiation, both dangerous and benign. Sources can be directed toward a target such as X-ray machines or can sim-

ply be electric and magnetic fields (EMFs) that emanate from electrical equipment or power lines.

The amount of radiation that a person is exposed to is called the radiation dose or dosage. There are three types of doses: Absorbed dose is the amount of radiation energy that is deposited per unit mass of the target; it is usually measured in roentgen absorbed dose, or rads. Recently, rads are being replaced by grays, which equal 100 rads. Equivalent dose is the absorbed dose that has been adjusted for the biological effect produced by the particular type of radiation that is being measured; it is measured in roentgen equivalent man, or rems. The committed dose, the third type, accounts for continued exposure over decades or even a lifetime. Most daily doses of personal radiation are measured in millirems (mrems).



Checking for drum leakage at the low-level radioactive waste disposal facility, Idaho National Laboratory, ca. 1977 (DOE)

## TYPES OF RADIATION

There are several types of radiation to which people can be exposed. The most common is electromagnetic radiation that is emitted by the Sun and stars as well as many manufactured devices. The electromagnetic (EM) spectrum is classified by the wavelength and frequency of the waves in the radiation. The long-wavelength, low-frequency, and low-energy radiation is considered to be nonionizing radiation. The end of this side of the EM spectrum is characterized by amplitude modulated (AM) radio, shortwave radio, frequency modulated (FM) radio, and television, in order of increasing frequency and shorter wavelength. The next are microwaves, radar, infrared light (IR), and finally visible light. The EM radiation with shorter wavelength, higher frequency,



**Pinellas Plant, St. Petersburg, Florida, ca. 1979** (*Time Life Pictures/Department of Energy/Getty Images*)

and higher energy than visible light is ionizing radiation. In increasing order, they are ultraviolet radiation (UV), X-rays, and gamma radiation. Ionizing radiation is damaging to human health.

The age-old enigma of photon release in EM radiation means that it can also be included in the particle emission radiation. When radioactive elements decay, they convert from a parent isotope to a daughter isotope. This decay includes the emission of particles that have atomic number, mass, and charge. By removing such particles, the atom converts from one element to another through a decay series. The largest particle that can be emitted is an alpha particle. It is equivalent to a helium atom in mass and charge. Although the decay is fairly energetic, because of their mass, they only travel about one-half inch (1 cm) before they use up energy. Their size makes them unable to penetrate paper, skin, glass, and most substances. They can only be damaging in cuts or internal organs. A beta particle, or betatron, is essentially an electron that is emitted during beta decay in which a neutron is converted into a proton. Their smaller size allows them to penetrate paper and some solids, although they cannot penetrate skin. They are only hazard-

ous to the health if they are ingested. Gamma and X radiation can penetrate most substances. That is why X-rays are used to probe the interior organs and bones.

Electric and magnetic fields (EMFs) are lines of force that surround any operating electrical device, as well as transmission lines and electrical distribution equipment. EMF can be subdivided into three types. Extremely low-frequency (ELF) fields generally have frequencies up to 300 Hz. Intermediate-frequency (IF) fields have frequencies between 300 Hz and 10 Mhz, whereas radiofrequency (RF) is between 10 Mhz and 300 Ghz. ELF is emitted from power supplies and electric appliances, IF is emitted from computer screens and security systems, and RF is produced by cell phones, television, radio, and microwave ovens.

### SOURCES OF RADIATION

There are several major sources of radiation: extraterrestrial, material, and equipment or anthropogenic. Extraterrestrial includes both the EM spectrum (solar) already described and cosmic radiation. Cosmic radiation is that radiation generated

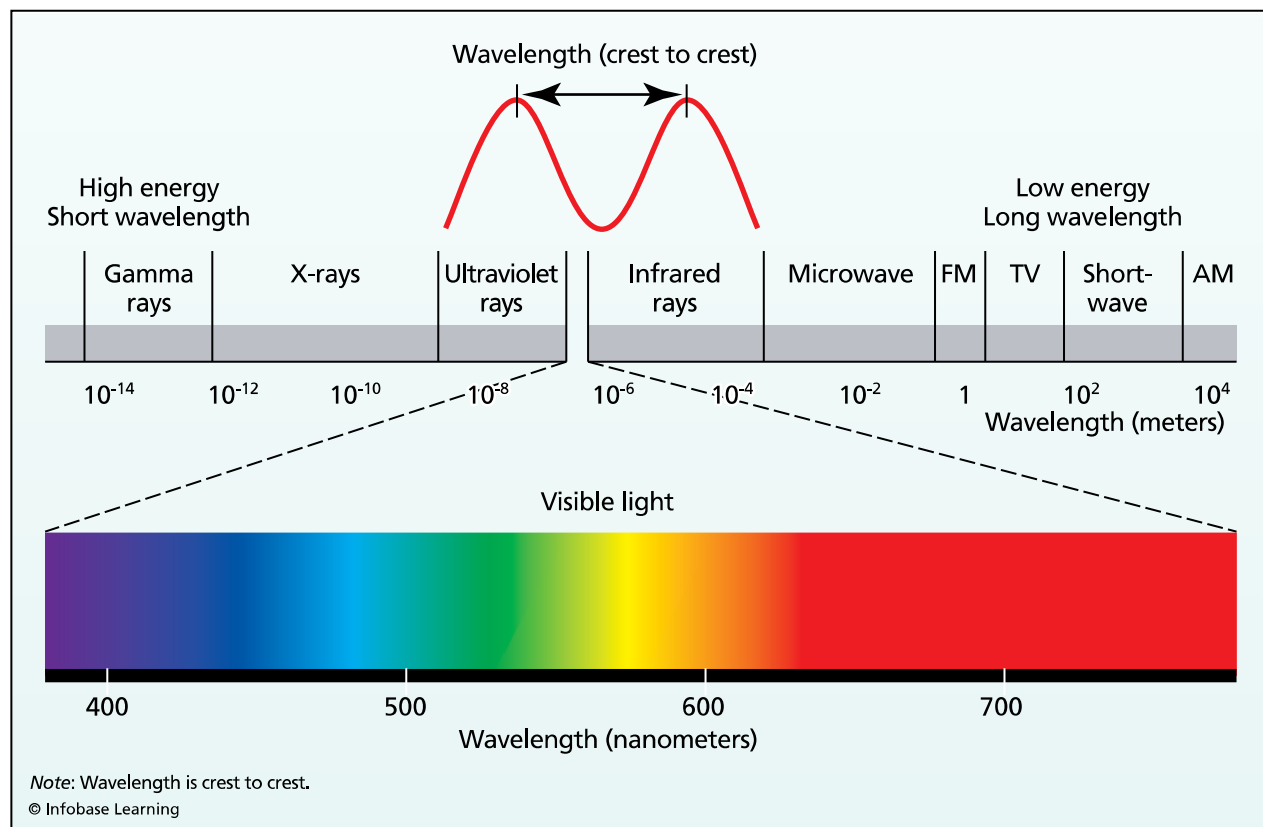


from outer space and by the Sun: It provides a constant bombardment of the Earth and contributes about 8–13 percent of the background radiation of Earth. There is direct radiation from space generally in the form of microwaves, but it is also from interaction of the atmosphere with cosmic rays.

Cosmic rays are highly charged particles that strike the Earth's atmosphere. About 90 percent of the particles is protons, 9 percent is helium atoms, and 1 percent is electrons. Cosmic rays originate from neutron stars, supernovas, and black holes outside the solar system but both within and outside our galaxy, though the Sun also emits anomalous low-energy cosmic rays from solar flares. There are primary cosmic rays, which are emitted directly from the source, and secondary, from collisions with other particles in space. When cosmic rays enter the Earth's atmosphere, they collide with oxygen and nitrogen molecules and produce a cosmic ray shower of mesons, unstable isotopes, gamma radiation, and neutrons. It is these interactions that change nitrogen 14 into carbon 14, which is commonly used for dating.

Cosmic rays are directed around the Earth by the magnetic field and are responsible for the aurora borealis. They are generally stronger at higher elevations but are dominated by protons very high in the atmosphere and more damaging neutrons lower in the atmosphere. Flying in an airplane increases the dosage from the cosmic radiation that results from interactions. For a typical cross-country flight, the dose is 2–5 mrems, which is generally small. People who fly often or fly near Polar regions, however, can be exposed to significant amounts of radiation, which could affect their health.

Earth materials also emit radiation. There are radioactive isotopes in most rock and soil but almost always in very small amounts. The common radioactive elements include uranium, radium, thorium, potassium, strontium, and radon, among others. Typically, elements within a decay series all occur together. A decay series is a step-by-step transition from a radioactive parent element through a series of daughter elements until a stable, nonradioactive daughter is reached. Decay series may have several tens of steps. Parent uranium decays to radium and



**Diagram showing the electromagnetic radiation spectrum of wavelengths in meters with illustrations of the relative wavelength sizes. The radiation is divided into ionizing and nonionizing and subdivided into types by common name. Illustrations of sources are also shown.**

then to radon on its way to stable lead. Depending upon the particular isotope, it may emit alpha or beta particles, but almost all emit gamma radiation. In some cases, these elements may be concentrated in a deposit. In these areas, there is risk of exposure to excessive amounts of gamma radiation, or, in the case of radon, alpha particles. In one case in Africa, so much uranium was concentrated in one place through natural processes that it began a nuclear reaction.

These types of occurrences of radioactive isotopes are called naturally occurring radioactive minerals, or NORM. If earth materials are processed and the radioactive minerals are removed as waste, they can produce dangerous concentrations called technologically enhanced naturally occurring radioactive minerals, or TENORM. The most common TENORM radioactive elements are uranium, thorium, and radium, which are derived from mining and mineral processing, oil and gas production, and drinking water and wastewater treatment.

There are also radioactive materials that are created by human activity whether on purpose or by mistake. The best known of the anthropogenic radioactive materials are used for defense, such as plutonium, or as a result of these activities, such as tritium. The other major uses of these materials are in medical procedures, sterilization, and some industrial applications. Many such isotopes are produced in a research grade nuclear reactor. Many are used instead of natural materials because the dosage and duration can be controlled better. The most common of these materials are cobalt 60, cesium 137, and technetium 99. Exposure can occur through medical procedures (mostly cancer treatment or diagnostic tests), to health care professionals applying these procedures or sterilizing instruments, in radiography during metal production, in sterilization of some foods and water, or through contact with the waste from any of the other uses.

The final sources of radiation are equipment and machinery. The simplest example of this is medical X-rays. This equipment generates X-rays directly to pass through parts of the body and onto special X-ray film to image the organ, tooth, or bone of interest. When X-ray equipment first became available, the equipment was leaky, was too powerful, and was used in too many applications, in shoe stores, for example. Nuclear power plants produce a lot of gamma radiation that can similarly pass through substances. That is why shielding by using lead or some other material that inhibits passage is very important. Other equipment bombards materials with high-energy particles, which, in turn,

generate secondary X-rays. This occurs mainly in high-energy analysis or related processes to which the public has very little access.

An enormous amount of equipment that is used every day produces EMF. Virtually all appliances, audio and video equipment, and computers produce it. The big scare in the past was the use of cellular phones. These are pressed against the skin for extended periods and produce EMF. Many studies have been conducted to determine whether there is a link between usage and disease, but none has yet been found.

### HEALTH EFFECTS OF RADIATION EXPOSURE

Ionizing radiation causes the most damage of any type of radiation exposure. Health effects from short-term high-dose exposure take the form of burns or radiation sickness. The more severe effect, radiation sickness, or radiation poisoning, produces a number of symptoms depending upon dosage. For an exposure of 5–10 rems, there can be rapid changes in blood chemistry. At 50 rems, nausea sets in within hours. At 55 rems, fatigue is added to the list of symptoms, and at 70 rems, vomiting begins. For an exposure of 75 rems, hair loss takes place within two to three weeks. At 90 rems, diarrhea begins, and at 100 rems, hemorrhage takes place. An exposure of 400 rems can be fatal within two months. At 1,000 rems, there are destruction of the intestinal lining and internal bleeding that ultimately leads to death within one to two very painful weeks. At 2,000 rems, damage to the central nervous system and loss of consciousness occur within minutes, and death follows in hours to days.

Long-term chronic exposure to low levels of ionizing radiation can also produce health effects. The main effect is cancer of many parts of the body. It can damage deoxyribonucleic acid (DNA) and produce genetic problems that can be passed on to offspring. If a pregnant mother is exposed to radiation, the fetus can be damaged as well.

Ingestion and inhalation of radionuclides can also cause severe health effects, typically over a lifetime of exposure. Radon is the most dangerous radiation source and the most dangerous environmental hazard. Unlike ionizing radiation, radon mainly damages human health with particle decay and specifically alpha decay. Normally, alpha decay is not a worry because the particle can only travel about  $\frac{1}{2}$  inch (1 cm) and cannot penetrate anything. The problem with radon is that it is a gas and is inhaled in indoor air. It decays to polonium, a solid that sticks to the lung tissue or to dust that

then attaches to lung tissue. The alpha decay that polonium undergoes can cause the cells in the lung tissue to mutate, potentially leading to lung cancer. It is estimated that some 25,000 lung cancer deaths per year in the United States are the result of radon exposure.

Ingestion of radioactive iodine leads to high levels in the thyroid gland. The thyroid takes in iodine and does not discriminate between stable and radioactive. For this reason, it leads to increased incidence of thyroid cancer. Strontium 90 and radium 226 behave similarly to calcium in the bloodstream. They accumulate in the bones and teeth and contribute to increased incidence of bone cancer. Radon can also be ingested within water. It can travel throughout the body in the bloodstream. Theoretically, it could increase the incidence of all types of cancer, but so far it has only been linked to an increase in leukemia.

Solar radiation in general and all of the forms of ultraviolet radiation cause the severe negative health effects over a long term of exposure. They can also cause skin burns and even eye damage in acute exposure, as anyone who has fallen asleep at the beach will attest. These burns can be severe and result in skin damage to the point where other symptoms such as fever, headache, fatigue, and nausea appear. This condition is locally referred to as sun poisoning. Long-term exposure can increase the likelihood of skin cancer. Solar radiation, in general, is considered a known human carcinogen. Increases in skin cancer, primarily melanoma, as well as melanoma of the eyes and non-Hodgkin's lymphoma, were found to increase with exposure. Broad-spectrum UVR is also considered a known human carcinogen and also increases the incidence of eye and skin tumors. It has also been shown to cause DNA damage. Each of the components of UVR, Ultraviolet-A (UVA), UVB, and UVC, is considered reasonably anticipated to be a human carcinogen, all increasing the incidence of skin cancer. The damage to DNA by UVR is caused by UVB and UVC; UVC is the more damaging. Fortunately, that is the wavelength that is best absorbed by ozone, and very little reaches the surface in the midlatitudes. Therefore, UVB does about 90 percent of the genetic damage.

EMF is emitted by numerous electrical devices and especially electrical distribution facilities. The only sure health effect of EMF is general heating similar to a microwave oven. Studies on the effects of living under power lines have yielded conflicting results. Some have claimed an increased incidence of childhood leukemia from a purely epidemiologi-

cal approach. It is for this reason that the National Institute of Environmental Health Sciences of the National Institutes of Health concluded that exposure to ELF fields like those produced by power lines is a possible cause of cancer. The International Association for Research on Cancer of the World Health Organization agreed and issued the same ranking. The problem is that studies on laboratory animals found no such link, and many scientists believe that there must be another causative link.

### DAILY RADIATION DOSE

An average individual receives a daily dose of radiation from several common sources. The average equivalent dose for a person in the United States is 360 mrems. Some professions may increase exposure, as may some personal habits. The common sources of radiation include cosmic radiation that depends upon elevation. The higher a person lives, the more cosmic radiation he or she receives. Similarly, people who regularly travel by air are exposed to higher levels of radiation. Both of these sources can be significant, up to 100 mrems or more apiece. There is a terrestrial source of radiation from earth materials that depends upon where a person lives. In the Gulf Coast and Atlantic Coastal Plain, the average dose from the earth is 23 mrems. Within the body, radiation can occur in food and water, air, a plutonium-powered pacemaker, and porcelain crowns or false teeth. The major sources are radon in air at 200 mrems, depending greatly on where a person lives, and the pacemaker at 100 mrems. Radon is commonly the greatest source of environmental radiation. There are a variety of very low-level sources of radiation such as X-ray inspection of luggage, gas lantern mantles in camping, weapons test fallout, stone and cement building construction, television viewing, computer use, proximity to a coal or nuclear power plant, use of a home smoke detector, and nuclear medical procedures. Besides the last one, most are 1 mrem or less. Medical X-rays are a much higher dose, at 40 mrem apiece.

*See also* COBALT; RADIOACTIVE WASTE; RADIUM; RADON.

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**radioactive waste** Radioactive waste contains either radioactive substances or materials that have been exposed to radioactive substances or radioactivity for long enough periods to make them a health concern. Although radioactive substances have been used for a long time, their disposal has only become an issue in about the past 50 years. Radioactive waste is divided into two types: low-level and high-level.

### LOW-LEVEL RADIOACTIVE WASTE

About 99 percent of all radioactive waste is classified as low-level. It is expected to remain of concern for about 300–500 years. The sources of most low-level radioactive waste are hospitals. It primarily results from medical treatments, radiation equipment, materials that have been exposed to radiation, and the handling of radioactive substances. The objects that make up low-level waste may include syringes, bottles and vials, cloth, or tools. Other major sources of low-level radioactive waste are research laboratories and manufacturing facilities. Industry, universities, and the military all conduct research using radioactive substances. The objects classified as waste include laboratory clothing, tools, syringes, and containers but may also include substances that have been irradiated in a nuclear reactor.

Although the Low-Level Radioactive Waste Policy Act of 1980 requires states to develop regional low-level waste repositories, few have complied. Over the past few decades, the number of repositories has actually decreased as the cost of disposal has soared. The residents of many states refuse to have nuclear waste stored near them.

Low-level waste is stored in drums either above- or belowground. The rusting and decay of the drums pose a threat to local groundwater supplies. Currently, the best place to store such waste is in shallow excavations above the water table, preferably in arid areas. The repositories should be as far from populated areas as possible.

### HIGH-LEVEL RADIOACTIVE WASTE

High-level radioactive waste is produced by nuclear power plants and the military. It is extremely dangerous, and great pains must be taken to protect both humans and nature from it. The most common of high-level radioactive wastes are spent fuel rods from a civilian nuclear power plant. These rods and other parts from decommissioned plants make up 94 percent of the radioactivity of all high-level waste. These components and most other forms of high-level waste are dangerous for thousands to millions of years. For example, plutonium must be kept away from the natural environment for at least 244,000 years, and there are longer-lived radioactive substances.

The major problem with high-level radioactive waste is what to do with it. There are about 430 nuclear power plants operating in 35 countries and potentially more in the future if several countries that are developing nuclear programs are truly not interested in weapons of mass destruction, as they claim, and their nuclear programs are for peaceful purposes.

*See also* COBALT; RADIATION; RADIUM; WAR AND POLLUTION; YUCCA MOUNTAIN WASTE REPOSITORY.

**radium** There have been numerous health scares nationwide about high levels of radium in drinking water. In many cases, the sources of these elevated levels are natural materials, and, as such, they generally cannot be removed and no person or company can be held liable. Areas with such natural problems include much of the western United States and especially parts of California, Nevada, Idaho, and Montana; midwestern states such as Minnesota and Wisconsin; and most of the crystalline Appalachians, including nearly the entire states of Maine and New Hampshire. Some anthropogenic sources such as radium dumps around old watch factories in New Jersey and Michigan have also produced dangerous conditions. It is the debate over whether a problem is natural or anthropogenic that keeps radium in the limelight of environmental problems. Its notoriety would not otherwise have been expected because radium has been found in only 18 of the first 1,177 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priority List) in which it was analyzed. Yet, on the 2007 CERCLA Priority List of Hazardous Substances, of the 275 hazardous substances, radium 226 ranks number 95, radium 228 ranks number 106, and general radium ranks number 100. It is the wide distribution, health threats, and uncertainty of its source that make radium such a danger.



### PROPERTIES, USE, AND PRODUCTION

Radium is a naturally occurring radioactive metal that occurs in the form of a silver-white solid in pure form but is more commonly in compounds. It is present in virtually all rock, soil, and sediments as well as air and groundwater in many areas. It occurs in numerous isotopes that are daughter products in the radioactive decay series of uranium and thorium. The two most common isotopes are radium 226 and radium 228, daughters of uranium 238 and thorium 232, respectively. It, therefore, is more common around uranium deposits and especially uranium mining operations. Radium is luminescent (glows in the dark) and a good source of gamma radiation. It is most abundant in the mineral pitchblende, but it also occurs in salts such as radium nitrate, chloride, iodide, sulfate, and carbonate.

Radium was discovered by the French Nobel Prize winner Marie Curie, in 1898, in the mineral pitchblende, but it was not isolated in elemental form until 1911. When it first came into use in the early 1900s, it was added to a variety of common products such as tonic, toothpaste, ointments, and elixirs, until it was banned because of the adverse health effects. Its luminescence and phosphorescence when mixed with phosphorus gave it broad use in instrument panels, watch and clock faces, and anything else that glowed in the dark. This application continued through World War II and, in some cases, until the early 1960s. More recently, it was used as a radiation source in cancer treatment. Radioactive seeds that were planted in tumors were first composed of radium, but more recent applications largely use cobalt 60 as a source. Recent and current uses of radium include industrial radiography to detect flaws in metal parts and, mixed with beryllium, in oil well logging to detect different layers. It also has many minor uses in analytical research equipment and even on the tips of lightning rods to ionize the air, thus attracting strikes.

### ENVIRONMENTAL RELEASE AND FATE

Radium is ever-present in nature in very small quantities. It is even locally present in large quantities as the result of completely natural processes. Radium can never be rendered harmless by reactions or microbial activity. It can only be changed by natural radioactive decay with a removal half-life of 1,620 years for radium 226, 5.77 years for radium 228, and 3.64 days for radium 224. Radium is associated with uranium deposits, phosphate deposits, and certain rock types and geologic provinces. Anthropogenic radium in the atmosphere is primarily from coal-fired power plants and less commonly from

other burning of fossil fuel, windblown dust from uranium mining, and incineration of waste containing radium. The radium is diluted in the atmosphere and either settles out by gravity or is washed out by precipitation. The average residence time for fine particles in the atmosphere is about one to 10 days. The concentration of radium in glacial ice, however, has increased by a factor of 100 over the past 80 years, indicating that it may reside in air for long periods and be widely dispersed. The sources of this atmospheric radium are thought to be fossil fuels.

Anthropogenic radium in water and soil is primarily from runoff from uranium mining operations, air pollution fallout around atmospheric sources, lime slurry from water softening, fly ash disposal from incinerators, and coal burning. There is approximately 97 million tons (88.2 million metric tons) of uranium tailings in the western United States. Canada generates about 10 million tons (9 million metric tons) of uranium tailings per year. Radium in salts is generally increasingly soluble in water with increasing pH depending upon the minerals in which it is contained. Leachate from uranium tailings has been found to contain significant radium content. It is removed from surface water either by settling into the sediment or precipitating as sulfate, commonly with barium sulfate. Radium readily binds to soil particles and generally remains immobile under most conditions. Under certain relatively common chemical conditions, however, it may be leached into groundwater.

The other way radium can be removed from soil is through uptake by plants, which occurs quite readily. Grasses can take up radium, and cattle graze on the grasses. By this process, radium can enter in beef and milk. Aquatic organisms can similarly take up radium from water and sediment. Bioconcentration factors for fish are only one to 60 for fleshy parts but 40–1,800 for bones. Radium can also biomagnify up the food chain, posing particular danger for humans.

### HEALTH EFFECTS FROM EXPOSURE

There are no acute effects of exposure to radium unless the dosage is far beyond any dosage that a human would have even a chance of experiencing. Long-term, chronic exposure can lead to a number of health problems, but they typically take years to decades to develop. In general, the gamma radiation from radium will damage the closest body part. Workers who painted luminous dials licked their brushes to sharpen them only to have their teeth become weak and brittle. The term *radium jaw* was coined in 1924 to describe the loss of teeth among

these workers. Cataracts and cancer of the sinuses were much more common among this group than among the general population, as well. From 1925 to 1965, a number of women were treated with radium for uterine bleeding disorders. This group had a greater incidence of uterine, colon, and genital cancer, as well as leukemia. General application of radium also has adverse effects. From 1946 to 1950 in Germany, young tuberculosis patients were injected with radium and were subsequently significantly shorter than the general population. It also causes anemia and greatly increases incidence of bone cancer and generally increases incidence of liver, breast, lymphatic, thyroid, and pancreatic cancer, as well as leukemia, among other cancers. The EPA, National Academy of Sciences, and several other agencies all consider radium a known human carcinogen. The greatest public health danger of radium, however, is that it decays to form radon, a far greater threat.

### REGULATIONS ON HUMAN EXPOSURE

Federal agencies limit the exposure of the general public to radium. The EPA set a maximal level of radium in drinking water at 5 picocuries per liter for any combination of radium 226 and radium 228. They further set a limit of radium 226 in soil from mine tailings at 5 picocuries per gram for the top 15 cm and 15 picocuries per gram at deeper levels. The National Emission Standards for Hazardous Air Pollutants limit radium emission to air to 10 millirems. The Uranium Mill Tailings Control Act restricts the disposal of waste uranium at mines and processing plants.

*See also* BIOACCUMULATION AND BIOMAGNIFICATION; COBALT; LEACHATE; PHOSPHORUS; RADIOACTIVE WASTE; RADON; SUPERFUND SITES.

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**radon** Radon is a naturally occurring odorless, colorless radioactive gas that is estimated to be responsible for as many as 25,000 deaths per year of lung cancer in the United States alone. These statistics from the U.S. Environmental Protection Agency (EPA) make radon the most dangerous environmental hazard. On the 2007 CERCLA Priority List of Hazardous Substances, of the 275 most dangerous pollutants, radon ranks number 105. Radon is just one step in the decay series from uranium 238 to lead (Pb) 206, both of which are naturally occurring. There are about 22 steps in this decay series, in which a series of alpha and beta decays transform the parent uranium atom into radioactive daughter isotopes of a number of elements. One step in this series is radium 224. If the radium is on the surface of a mineral, when the next alpha decay occurs, a process called alpha recoil may eject the radioactive atom off the grain and into the pore space within sediments or soil. Radon 222 is the only gas in the decay series; all others are solid. It is also a noble gas and, therefore, will not react with any other substance; nor can it be filtered from the air by using conventional methods. Most radon is either released into the air or decays to the next step in the series while still contained within the same rock or soil pore space where it was released.

### ENTRANCE INTO INDOOR AIR

The problem occurs in a house that has a basement over soil or sediment containing radon. Virtually all soil contains some radon. Basements typically are not very tightly sealed, as they contain French drains, sump pumps, drains and/or holes, and cracks in the walls that permit soil gas to infiltrate the house. In the summer, there may not be much problem with infiltration because open windows eliminate pressure gradients and cooled air from air-conditioning is dense and sinks, pushing air through the openings and out of the house. In winter, however, when the air in the house is heated, it rises. Rising indoor air pulls air from the basement and draws soil gas through the openings in the basement walls and floor. This air commonly contains radon. Forced air heating and cooling systems may

do this all year long. Radon is then in the house and free to circulate.

### HEALTH EFFECTS OF RADON EXPOSURE

Radon itself is not particularly dangerous, but because it is radioactive, it changes to another element. The half-life of uranium radioactively decaying to its daughter product lead is a slow 4.6 billion years, but radon decays to its daughter polonium 220 much faster. The decay half-life (the time for one-half of the

mass of radon to change to polonium) is only 3.82 days. Polonium is a solid that reacts quickly. If the radon is in a person's lungs when the change takes place, the polonium adheres directly to lung tissue. If the radon is in air, the polonium may stick to a dust particle and be inhaled into the lungs. Polonium undergoes an alpha decay, emissions of a short-lived, heavy particle, producing 7.6 million eV in a matter of seconds. Normally, alpha decays or particles are not dangerous at all. At 4 atomic mass units per atom, they are so large that they cannot penetrate glass

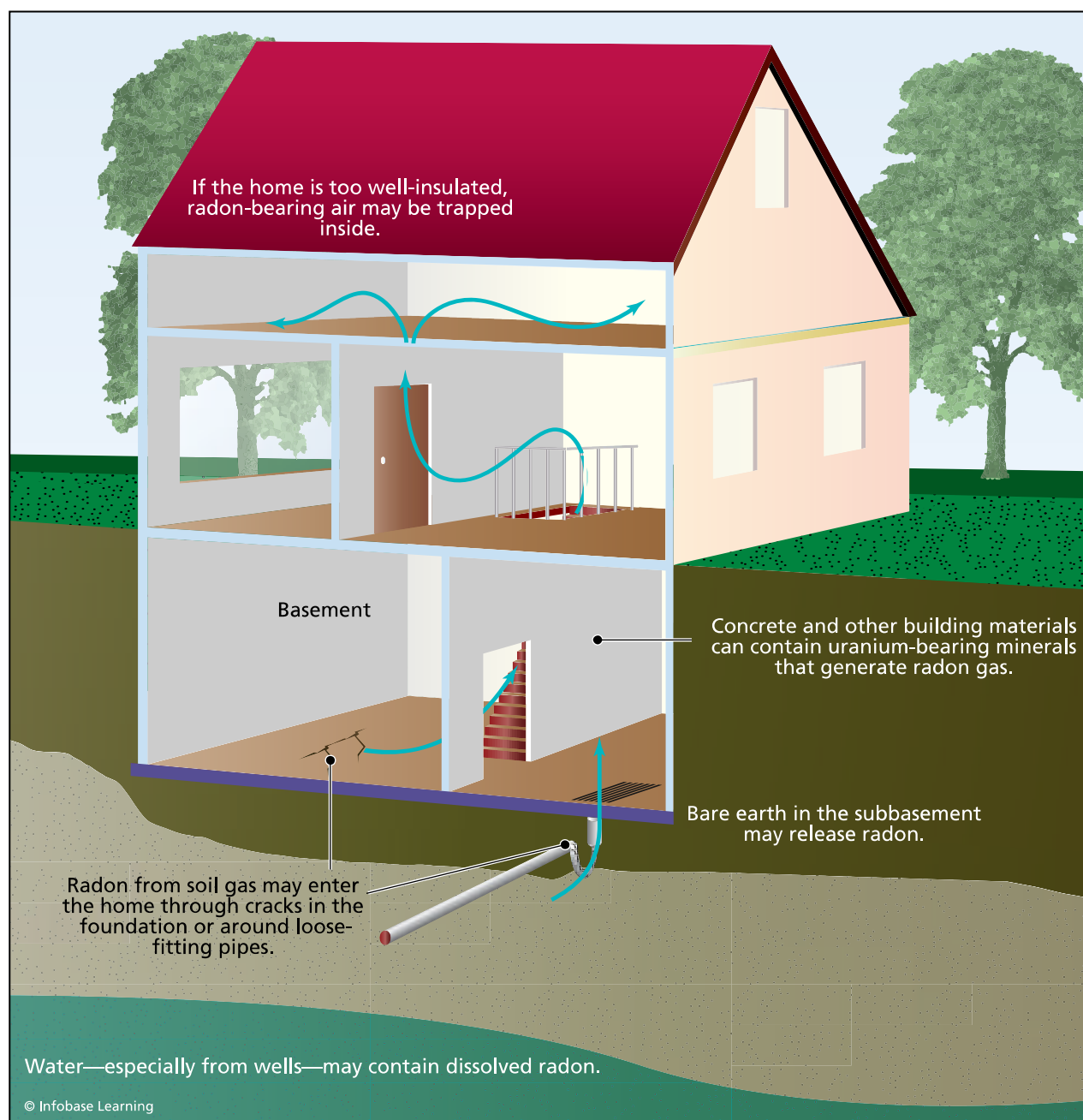


Diagram showing potential entries for radon into a building, where it may accumulate to dangerous levels

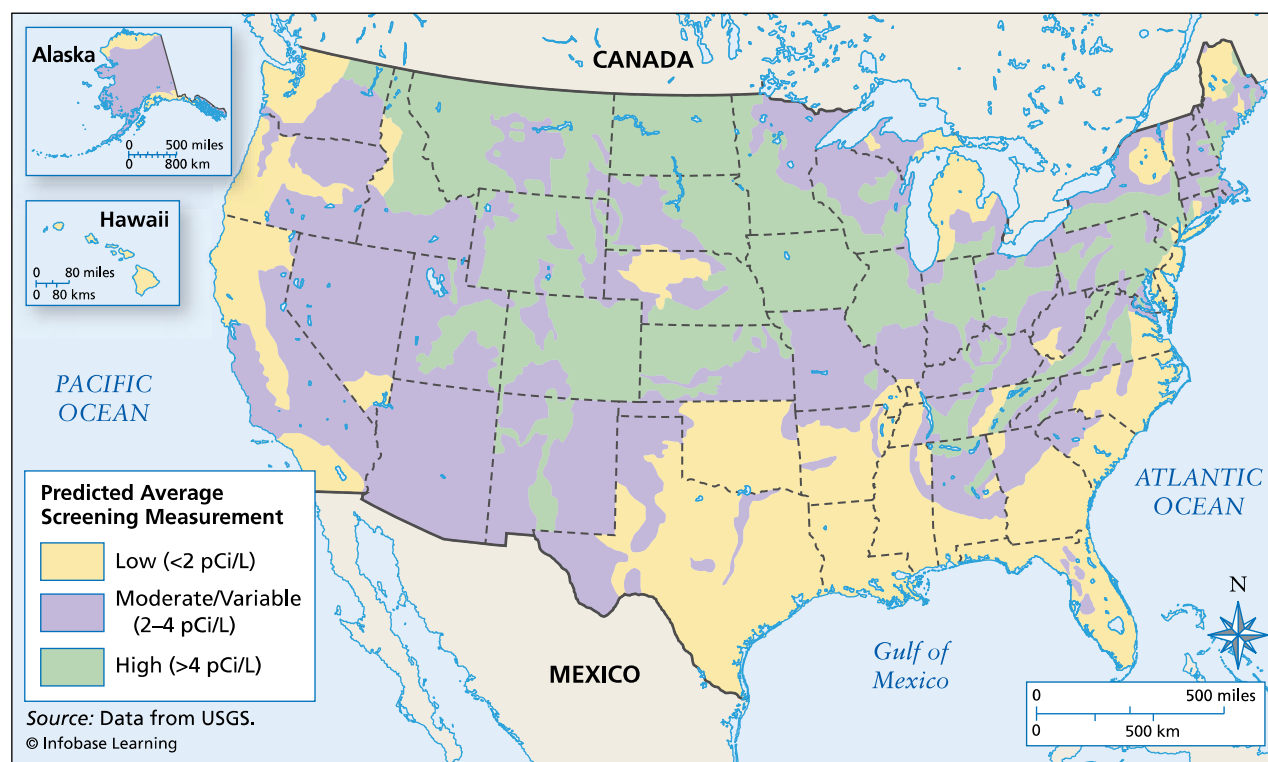
or paper, and they are so heavy that they can only travel about a half-inch (1 cm) before exhausting their energy. When sticking directly to lung tissue, however, the alpha particle can cause the attached lung cell to mutate. Each additional decay in the series all the way to lead 206 can cause additional damage to the same cell. Lung tissue has resiliency and can dispose of the random mutated cell without much problem. If there are a number of mutated cells, however, the immune system may be overwhelmed, and the person affected may develop lung cancer.

Radon was historically not considered to be a problem. The first indication that it might be was an epidemiological study in the 1970s of Swedish uranium miners who showed a significant increase in lung cancer relative to the general population. It was never suspected that radon could pose a threat to homes. A contributing factor to radon's becoming a health hazard was the energy crisis of the 1970s. In an effort to save energy, houses were sealed as tightly as possible to reduce the infiltration of outside air and loss of conditioned indoor air. Whereas previously radon concentrations were diluted by outside air, which contains little to no radon, in a tightly sealed house, radon could now concentrate in indoor air.

The first indication that indoor radon could pose a health threat was in 1982. The concentration of radon in the Swedish uranium mines was approximately 700 picocuries per liter (pCi/L), which was considered to be extreme compared to indoor levels. A home in Boyertown, Pennsylvania, however, was found to contain 3,200 pCi/L. This concentration is even more alarming when compared to the action level established by the EPA years later of 4 pCi/L. An action level means that remedial methods must be enacted to reduce the levels. Radon mania ensued through the 1980s and most of the 1990s. Homes could not be sold without acceptable radon test results. Charlatans ran amok with everything from jars to fly paper offering to test for and reduce radon. After a few years, however, methods were standardized and the industry settled into reputable companies. The highest indoor radon concentration ever recorded was in Clinton Township, New Jersey, at 3,500 pCi/L.

### MEASURING RADON IN HOMES

Radon in indoor air can be measured in several ways, the most common of which are the charcoal canister and the alpha track. The charcoal



**Generalized radon potential map of the United States based upon geology. It is a potential map because radon accumulation depends more on housing construction than on geology. If a house is built on a slab with no basement and with public water, there is no way to have a radon problem regardless of the geology. Therefore, the comparison can only be made for a specific type of house in each of these areas. (Source: USGS)**



canister is much most commonly used and is the only method used by building inspectors. With the basement sealed, the lid on a canister of activated charcoal is removed, and it is exposed to the indoor air for up to three days. The canister is resealed and sent to a laboratory for analysis, where the amount of radon daughters is determined. This method gives a snapshot of the indoor radon conditions and, therefore, is subject to weather, water usage, and other factors that can radically vary the concentrations. The alpha track method involves exposing a strip of alpha-sensitive film to indoor air for a period of three months. Alpha decays from the radon and its daughters leave small marks on the film, which are then counted to yield concentrations. This long-term test yields the average radon concentration in a building, which is more useful than the charcoal canister method as an indicator of exposure and threat to health. Radon is considered dangerous only for long-term exposure, on the order of tens of years.

Radon can also enter groundwater if the soil or sediment is saturated. It is released from the water if it is agitated and enters air. Water radon poses another problem for people who rely on wells for their household water needs. Radon can be released by simply running the water from the tap, but dishwashers, showers, and washing machines can also release much radon. Water can hold much higher concentrations of radon than air. The record is 2.5 million pCi/L, but levels in the tens to hundreds of thousands are not uncommon. The EPA recently set the action level at 10,000 pCi/L for water. A study at the University of Maine found that ingested water might also pose a threat. Subjects drinking water with moderate levels of radon were found to be exhaling air with significant radon levels after a 20-minute metabolic period. The radon was passing through their stomach and into their blood, circulating throughout their body, and leaving of their lungs with the regular metabolic carbon dioxide. All organs and blood are apparently exposed to radon through this process. The EPA and National Institutes of Health deem the dosage from this source to be too small for concern, but no rigorous epidemiological studies have been performed to prove this.

Radon may also result from industrial effects. Any industry that uses radium in its production has the potential to produce radon pollution. The most common culprits are old watch manufacturers. The luminous dial on analog watches is typically made of radium. Any industrial waste from these companies typically contains radium and, if improperly

disposed of, can cause an environmental hazard. The most famous case of this occurred in a Montclair, New Jersey, watch factory that tainted soil all around the town and into Glen Ridge and has taken decades for cleanup.

See also AIR POLLUTION; INDOOR AIR POLLUTION; RADIATION; RADIOACTIVE WASTE; RADIUM; SUPERFUND SITES.

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#### Reactive Metals Extrusion Plant Ashtabula, Ohio (1990–present) Soil Pollution

The dedication, creativity, and commitment of the people who worked in places such as the Reactive Metals Extrusion Plant (RMEP) in Ashtabula, Ohio, were part of the reason that the United States survived the cold war. About 60 miles (96.6 km) northeast of Cleveland on the shore of Lake Erie, the 26-acre (10.5-ha) RMEP site was part of the industrial complex that manufactured nuclear weapon components. In 1962, the Atomic Energy Commission (Nuclear Regulatory Agency, or NRC, after 1974)

licensed the placement of a 3,900-ton (3,538-metric-ton) extrusion press at Ashtabula. For the next 30 years, under contracts with the U.S. Department of Energy (DOE), RMEP manufactured metallic uranium tubes, rods, and forged uranium parts for use in atomic weapons. These products were cut, straightened, acid bathed, and machined before shipment to other weapons manufacturing facilities.

As did similar plants in Dayton and Fernald, Ohio, and Oak Ridge, Tennessee, RMEP operated under high security and with a single mission; to create reliable nuclear weapons as fast and inexpensively as possible. This was a time when America felt very threatened by the spread of communism and was competing in an all-consuming arms race with the Soviet Union and China. Even the great secrecy of nuclear weapons plants, however, could not hold off the public pressure that was building for environmental disclosure. By the early 1980s, with the end of weapons production and the need for plants such as RMEP starting to decline, it was time to assess the environmental damage caused by the operations.

### POLLUTION OF THE SITE

RMEP emitted mixed uranium metal and oxide dusts through six stacks and, over its operational life, released approximately 1,900 pounds (850 kg) of uranium. The soil around RMEP was contaminated with tiny fragments of uranium, as well as technetium 99, a fission product from recycled reactor material, and other metals used in its processing operations. These metals were released from process stacks and settled as fallout around the plant. They were also washed out of storage areas by rainfall and snowmelt. Core samples of the top two inches (5 cm) of site soil contained uranium concentrations ranging from 1.1 pCi/g to as high as 2,439 pCi/g. A typical background value for uranium in soil in this part of Ohio is 4.4 pCi/g or less. The NRC average limit of uranium in soil intended for unrestricted use is 35 pCi/g.

The amount of radiation exposure is usually expressed in a unit called a millirem (mrem). In the United States, the average person is exposed to an effective dose equivalent of approximately 360 mrem whole-body exposure per year from all sources. As radiation moves through the body, it either causes no damage to cells, damages cells in a way that they can repair, or damages cells in such a way that the damage is passed on when the cell reproduces. In the first two cases, there is no lasting health effect. In the third case, a delayed health

impact, such as cancer, may develop. If the dose is high and the exposure is long, the radiation may kill the cell. If this occurs, an immediate health effect is observed such as burns, nausea, or even death. Many radioactive substances tend to accumulate or concentrate in specific “target” organs such as the kidneys or thyroid. When this occurs, that organ receives a higher dose than other organs or tissues. This occurs because some radioactive materials are chemically similar to essential human nutrients. A commonly cited example is strontium 90, which is very similar chemically to calcium. Once it is ingested, the body will metabolize strontium in the bone in the same way it does calcium. Certain radionuclides are carried throughout the entire body. Tritium is an isotope of hydrogen, and, since hydrogen is part of the water molecule, tritium is carried to all parts of the body and delivers a dose to all tissues. Information on how radiation affects human health has been learned primarily from studies of survivors of the atomic bombing of Japan and industrial accidents such as at Chernobyl.

### THE CLEANUP

At RMEP, the widespread on-site contamination with estimated volumes of contaminated soil up to 64,000 tons (58,060 metric tons) made its removal and off-site disposal prohibitively expensive. Instead, the Department of Energy decided to use a remedial technique known as soil washing to recover the uranium and reclaim the land around the site.

Developed in Europe in the 1980s, soil washing is an ex situ remedial technique that uses water in combination with chemical additives to extract or wash out the contamination. The types of additives used include soaps, chelating agents to bond with metals, acids to dissolve them, and alkalis to precipitate them. Once the contaminant is separated, it can be properly disposed of and the clean soil returned to the site.

Soil washing works best if contaminants can be transferred to the wash fluid or concentrated into one part of the soil, most commonly the silt or clay fraction. After the contaminated soil is excavated, it passes through a series of sieves that separate the coarser grains from the finer silt and clay particles. The coarse sand and gravel are generally not contaminated and can be returned to the excavation without further treatment. A solution is then mixed with the silt and clay, and the resultant slurry is fed to a flotation or frothing/foaming device. Once it is there, the contamination can be skimmed off and

the clean silt and clay allowed to settle for drying, testing, and return to the excavation. If the contaminant cannot be separated easily from the silt and clay, then it is shipped for off-site disposal after drying. This process is more effective in soil with high percentages of sand and gravel. Soil with a high clay and silt content does not respond well, as the contaminant tends to bind with those smaller soil particles and becomes tough to separate.

At RMEP, the DOE and its cleanup contractors constructed a carbonate extraction plant that has remediated more than 14,000 tons (12,701 metric tons) of radioactively contaminated soil. In this process, the uranium-contaminated soil is mixed with a sodium carbonate solution. The uranium is taken out of the soil and dissolved into the liquid to form a carbonate complex. This carbonate solution is run through a series of columns where the uranium is captured by special resins and later flushed out by using sodium chloride. The system in use at RMEP can process up to 10 tons (9.1 metric tons) per hour, with 85–95 percent capture efficiency. DOE's contractor, the developer of this process, has estimated that the system has saved more than \$300 per ton (\$273 per metric ton) over other remedial options.

The chief challenge to using soil washing is the management of the water and chemical additives that are mixed with the soil. For a soil washing system to be cost-effective, the wash water and additives must be able to be recycled or reclaimed and be safe enough eventually to discharge to the environment without requiring extensive treatment or creating another hazardous condition.

At the end of the project, DOE will cease all operations in Ashtabula, leaving the extrusion plant in compliance with less than 30 pCi/g of uranium in soil. It is unlikely, however, that the site will ever be used for residential purposes, and its anticipated future purpose is likely to be some sort of industrial or manufacturing operation.

See also COBALT; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; RADIOACTIVE WASTE; RADIUM; SOIL.

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#### Revelle, Roger Randall Dougan (1909–1991) American Oceanographer, Environmental Advocate

When Roger Revelle received the National Medal of Science from President George H. W. Bush in 1990, he concluded that it was for being the "grandfather of the greenhouse effect." No one disagreed that he deserved the title, and it is for this achievement that he is best known, but his contributions to society are many. The *New York Times* called him "one of the world's most articulate spokesmen for science." It is difficult to forget the name *Roger Revelle* as it appears as the name of a college at University of California at San Diego, on a research vessel at the prestigious Scripps Oceanographic Institution, and in the public health building at Harvard University, but recently it became even more prominent. The 2006 Oscar-winning documentary *An Inconvenient Truth* by the former vice president Al Gore correctly identifies Roger Revelle as the discoverer of global warming and the greenhouse effect, as well as Gore's personal inspiration. It is on this global level that Roger Revelle is revered.

#### BIOGRAPHICAL INFORMATION

Born on March 7, 1909, in Seattle, Washington, Roger Randall Dougan Revelle was raised in Pasadena, California. He was recognized as a prodigy from a young age—he entered Pomona College, California, in 1925 at age 16, intending a career in journalism, till a class in geology fascinated him and he changed majors. In 1928, he met Ellen Virginia Clark, whom he married in 1931. Clark was a student at nearby Scripps College and the grandniece of the college's founder, Ellen Browning Scripps. Revelle graduated with a bachelor of science degree in 1929 and continued his graduate studies in geology



**Dr. Roger Revelle, head of Scripps Institute of Oceanography, March 1961** (Photo by Fritz Goro/Time Life Pictures/Getty Images)

at the University of California at Berkeley in 1930. His area of specialization was oceanography, and in 1931 he received a prestigious research assistantship, fortuitously at the Scripps Institute of Oceanography in La Jolla, California. During his time at Scripps, he also served as instructor. Revelle received his Ph.D. in 1936 and earned a postdoctoral fellowship at the Geophysical Institute in Bergen, Norway. In 1937, he returned to the United States to a position of research associate at Scripps Institution and part-time lecturer at the University of California at Los Angeles.

Roger Revelle was a reserve officer in the U.S. Navy and was called to duty in 1941. In 1942, he was assigned to the Bureau of Ships, where he conducted oceanographic research. By 1945, he was on the staff of the commander of amphibious forces for the Pacific fleet, where he helped plan the invasion of Japan. When the war ended, Revelle remained in the navy to participate in the first postwar atomic test

on Bikini Atoll, code-named Operation Crossroads. He led the Crossroads scientific program to study the effects on marine life, as well as remnant radiation in the rocks and sediment. In 1947, Revelle was transferred to the Office of Naval Research, where he was appointed head of the Geophysical Branch. There he established a model to support research at universities, which would later be used for the National Science Foundation. Revelle retired from the navy in 1948 as a commander.

Roger Revelle returned to Scripps Institution in 1948 and became its director in 1951. Under his leadership, Scripps became one of the leading oceanographic institutions in the world. He greatly expanded the fleet, participated in research cruises, and was personally involved in most of the great discoveries. Revelle established or was a key participant in nearly every major international committee on the oceans. He was also the major force in making Scripps part of the University of California at San Diego in 1959–60 where he served as dean. During this time, Revelle took a leave in 1962–63 to serve as science adviser to secretary of the interior, Stuart Udall, when he was instrumental in gaining recognition and acceptance for the work of Rachel Carson, whose book *Silent Spring* was released that year.

Roger Revelle switched directions in his career in 1964, when he accepted a position as Richard Saltonstall Professor of Population Policy at Harvard University, where he also served as director of the Center for Population Studies. He was especially concerned with food production in relation to population growth and again made his mark on the forefront of the field. In 1976, Revelle returned to the University of California at San Diego to be a professor of science and public policy, the extent of semi-retirement as he would allow himself. Roger Revelle died on July 15, 1991, in La Jolla, California, at age 82 of complications related to cardiac arrest.

### THE GREENHOUSE EFFECT

Before the mid-1950s, it was assumed by the scientific community that any excess carbon dioxide produced by human industry would be quickly absorbed by the oceans, keeping the atmospheric levels relatively constant. The new technique of measuring carbon isotopes allowed Hans Suess to distinguish normal carbon from that produced by human activities in 1955. Roger Revelle recruited Suess for Scripps Institution, and the two published a seminal paper in 1957, clearly demonstrating, with Suess's techniques, that the amount of carbon dioxide was



increasing in the atmosphere as the result of human activities. Revelle also attracted Charles Keeling to Scripps in 1956, and he began systematic measurements of carbon dioxide in the atmosphere at Mauna Loa, Hawaii, and in Antarctica. This basic research would be the foundation of the study of greenhouse gases and global warming. As a result, Revelle was asked in 1965 to serve on the president's Science Advisory Committee Panel on Environmental Pollution; through his influence, for the first time, carbon dioxide from the burning of fossil fuels was recognized as a potential global problem. Revelle served on many other international panels, spreading the concern for global warming, but he is probably best known for a popular article published in *Scientific American* in August 1982. This article not only showed and explained the increase in atmospheric carbon dioxide, it also described the effects on the Earth, including the melting of glaciers and ice caps, thermal expansion of the ocean, shifting of climate belts, and changes to the ocean and atmospheric circulation patterns.

### PUBLIC AND PROFESSIONAL RECOGNITION

Roger Revelle was one of the most decorated scientists of all time. In addition to the awards mentioned, Revelle was elected to the National Academy of Science in 1958 and was awarded their Agassiz Medal in 1963. He was awarded the order of the Sitara-Imtiaz in 1964 by President Mohammed Ayub Khan of Pakistan for his work on waterlogging and salinity. He was awarded the Balzan Prize for oceanography and climatology in 1986 by President Francesco Cossig of Italy. The American Geophysical Union awarded Revelle its highest honor, the Bowie Medal, in 1968, as well as the Tyler Medal in 1986. The University of California at San Diego even named a medal for excellence in education in his honor.

See also AIR POLLUTION; CARBON DIOXIDE; CARSON, RACHEL; GLOBAL WARMING; GORE, AL.

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### Rocky Mountain Arsenal Denver, Colorado (1987–2012) Soil and Water Pollution

In the early days of World War II, the United States acquired, through the use of eminent domain, approximately 20,000 acres (8,000 ha) of flat, productive farmland 10 miles (16 km) northeast of Denver, Colorado. A massive round-the-clock building program then began, and, six months later, the nation's first chemical weapons and incendiary munitions manufacturing facility became operational. In the center of the country, far from more easily attacked coastlines, away from populated areas, and close to major rail lines, over the next four years the Rocky Mountain Arsenal produced more than 100,000 tons (90,718 metric tons) of gas, napalm, and other specialty munitions. It surpassed the combined German and Japanese production of these materials within the first year of production.

The Rocky Mountain Arsenal (RMA) was closed for a short time at the end of the war, but increasing tensions with the Soviet Union during the cold war and the need for incendiary munitions during the Korean and Vietnam conflicts resulted in the reactivation of the facility. Supplementing its purely military mission, RMA also helped manufacture the hydrazine and other rocket fuel that powered America's space program. Later, it leased a portion of the facility to Shell Oil Company for the manufacture of pesticides.

### POLLUTION OF THE SITE

During the 1960s and 1970s, chemical warfare agents continued to be produced at RMA, most notably GB nerve agent, better known as Sarin. RMA also played a major role in the decommis-



South Plants manufacturing complex at Rocky Mountain Arsenal, Colorado, ca. 1992 (© Wendy Shattil/Bob Rozinski)

sioning and destruction of obsolete and unwanted chemical and incendiary munitions. In order to manufacture and dispose of these munitions, RMA utilized enormous quantities of sulfur and chlorine with water. In addition, Shell Oil Company used water in its processing operations. This water was discharged into a series of unlined lagoons and holding basins. Liquids infiltrated and entered the regional groundwater system, and solids accumulated at the surface and sometimes washed into local streams and drainage swales. In other areas of the facility, chemicals from manufacturing and demilitarization processes were buried, incinerated, or simply poured into disposal trenches. At certain buildings, liquid wastes were discharged.

The community surrounding the RMA, a thriving suburb of Denver, began to notice the effects of these industrial activities. The availability of a reliable and plentiful supply of groundwater had been one of the key factors in the construction and operation of RMA, and this groundwater supply, which also served the surrounding communities, was being threatened.

## REMEDIAL ACTIONS

The army tried to remedy some of these problems through a number of short-term solutions. In 1956, a state-of-the-art waste holding evaporation pond with a capacity of 243 million gallons (918 million L) was installed with an asphalt liner and chemically sealed vitrified clay pipes that carried the liquid wastes. Despite this effort, by 1962, complaints about tainted groundwater in off-post drinking water wells were increasing. The army decided to drill a two-mile- (3.2-km-) deep waste injection well for the disposal of liquid chemicals. This well was intended to dispose of wastes far below the land surface in a geologic horizon that would not be used as a drinking water supply. Although it was not as efficient as planned, more than 170 million gallons (643 million L) of liquid waste was pumped into this well and permanently disposed of in the subsurface. Within a few years of its operation, however, a series of small earthquakes occurred in the generally aseismic Denver area. After a series of geologic studies, geophysicists concluded that the injection of liquid wastes deep into the subsurface by the RMA

disposal well was acting as a lubricant for a series of ancient faults and was causing the earthquakes. Deep-well injection at RMA ended shortly after that report was issued, and so did the earthquakes.

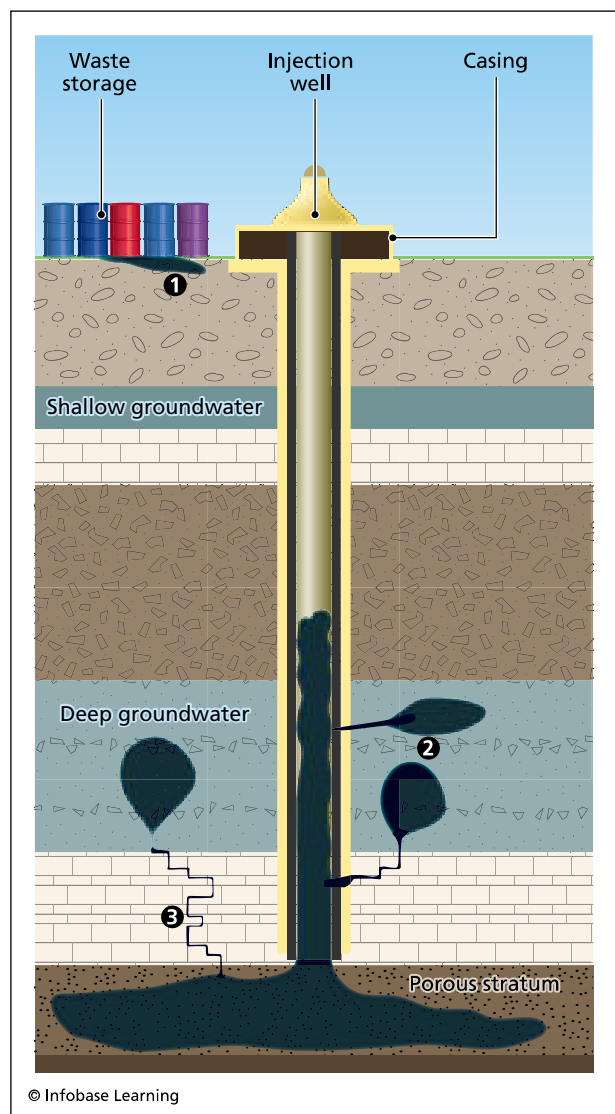
By the 1970s, it had become clear that RMA operations had severely affected local groundwater quality. The facility was added to the National Priorities List as a Superfund site in 1987, and its mission formally changed from military applications to environmental

restoration. Contaminants detected in groundwater include organochloride- and organophosphate-based pesticides; carbamate-type insecticides; chlorinated solvents, primarily tetrachloroethylene (PCE) and trichloroethylene (TCE); heavy metals; and feedstock chemicals used as raw products or intermediates in the manufacturing process.

Remedial efforts at RMA have cost billions of dollars and are expected to continue well past 2012. Four large pump-and-treat systems prevent the migration of contaminated groundwater from severely affected areas on- and off-post. More than 1.2 billion gallons (4.5 billion L) of captured groundwater is treated and either released to the area's municipal sewer system or recharged to help flush residual contaminants out of the ground. In other parts of the property, buried wastes have either been excavated, stabilized, and placed in secure disposal units on the property or been entombed in situ. This method involves surrounding the waste with low-permeability slurry walls and covering it with specially designed long-term earthen caps. Investigations continue on ways to address the products of more than 30 years of important and essential military manufacturing activities safely and cost-effectively. Shell Oil also has acknowledged its role in the spread of contamination and is working cooperatively with the army and state of Colorado to address soil and groundwater contamination related to its operations.

As cleanup operations began to improve environmental quality, government officials recognized they had a unique opportunity to restore most of this land to the public. In 1992, the Rocky Mountain Arsenal National Wildlife Refuge Act was passed and signed by President George H. W. Bush. This act allows the majority of the site to become a national wildlife refuge under the jurisdiction of the U.S. Fish and Wildlife Service. Portions of the property will be sold to local communities for road improvements and commercial development, but the vast majority of the 20,000-acre (8,000-ha) site will be restored and maintained for the enjoyment of the public. In 1997, approximately 6,000 acres (2,400 ha) of the site was removed from the National Priorities List, and in 2006 another 7,200 acres (2,880 ha) was transferred. This makes the Rocky Mountain Arsenal Wildlife Refuge one of the largest urban wildlife centers in the United States. It is habitat to bald eagles, bison, and more than 300 other species. Another 11,000 acres is scheduled for inclusion in the refuge by 2011.

See also INORGANIC POLLUTANTS; IN SITU GROUNDWATER REMEDIATION; ORGANIC POLLUTANTS; PCE; PESTICIDES; TCE.



**Illustration of a deep high-pressure injection well for hazardous waste like the type that was used in the Rocky Mountain Arsenal. The idea is to place the waste deep enough that it cannot affect humans or the environment. The three potential problems shown are: spills at the surface (1), leaks in the well casing (2), and leakage through rock strata (3). A new problem was found in the Rocky Mountain Arsenal when the wells started generating earthquakes.**

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# S

**Safe Drinking Water Act (SDWA)** The Safe Drinking Water Act (SDWA) was enacted by the U.S. Congress in 1974 as public pressure to regulate pollutants in the environment mounted. This legislation was originally designed to protect public health by regulating the nation's public drinking water supply. This initial legislation was amended twice, once in 1986 and again in 1996, to protect drinking water further with stricter and more far-reaching controls. They also provided some protection to the environment by considering the water sources such as rivers, lakes, reservoirs, springs, and groundwater wells. The SDWA authorizes the U.S. Environmental Protection Agency (EPA) to set the national health-based standards for drinking water. These standards protect drinking water against both naturally occurring and anthropogenic contaminants. The EPA, state governments, and water supply systems work together to make sure the standards are met.

The naturally occurring contaminants that are addressed by SDWA include microorganisms that are naturally contained in water and soil, radionuclides, nitrates and nitrites from soil, fluoride, and heavy metals, including arsenic, cadmium, chromium, lead, and selenium that are derived from bedrock and soil. Contaminants from human activities have a number of sources. Human and animal wastes are derived from septic tanks, and farms may contain bacteria and nitrates. Heavy metal contaminants are derived from mining, construction sites that use equipment and metal components, and older orchards. Other contaminants from outdoor applications include fertilizers and pesticides from agricultural and landscaping activities. There are industrial products and wastes from local factories and production and dis-

posal activities from industrial plants that are also monitored. Gas stations, dry cleaners, leaking home underground storage tanks (USTs), municipal and local landfills, and dumps are dominant sources of contaminants from urban and suburban residential areas. Even private residences generate contaminants from household wastes including solvents, used motor oil, paint and paint thinner, lead and copper from household plumbing, and even water treatment chemicals from wastewater treatment plants.

There are now about 170,000 public water systems that provide water to virtually all Americans at some point in their lives. More than 273 million Americans receive water from 53,000 community water systems. The EPA, individual states, tribes, municipalities, water supply systems, and the general public bear the responsibility for making sure these public water systems provide safe drinking water. The SDWA provides the organization for these groups to work together to accomplish this.

## DEFINITION OF WATER SUPPLIES

To be considered as a public water system, there must be at least 15 service connections or at least 25 people served per day for 60 days of the year. Single-residence (family) wells are not regulated by SDWA. The drinking water standards are applied to water systems on the basis of their type and size. Water systems are divided into the following categories:

*Community water system.* A community water system is a public water supply system that serves the same people throughout the year. Most residences, including homes, apartments, and condo-

miniums in cities, small towns, and mobile home parks, are served by these systems. There are approximately 54,000 community water systems in the United States.

*Noncommunity water system.* A noncommunity water system is a public water supply system that serves the public but does not serve the same people throughout the year. There are two types of noncommunity systems: nontransient noncommunity water systems and transient noncommunity water systems.

*Nontransient noncommunity water system.* A nontransient, noncommunity water system is a public water supply system that serves the same people more than six months per year, but not throughout the year. An example of such a system might be a regular academic year school (no summer activity) with its own water supply. There are approximately 20,000 nontransient, noncommunity water systems in the United States.

*Transient noncommunity water system.* A transient noncommunity water system is a water supply system that serves the public but not the same individuals for more than six months at a time. An example of such a system might be a rest area or campground where the water may be used throughout the year but the same people are not using it. There are approximately 89,000 transient noncommunity water systems in the United States.

## ESTABLISHING DRINKING WATER STANDARDS

The EPA has set primary drinking water standards according to the following three-step process:

- 1) Identification of the contaminant. The EPA identifies contaminants that may adversely affect public health and are occurring in public drinking water supplies with a frequency and at levels that are of concern. The EPA identifies these contaminants for detailed study and, using those results, determines the contaminants that may require regulation.
- 2) Determining maximal contaminant level (MCL). The EPA determines a maximal contaminant level goal for contaminants that meet the criteria for regulation. The MCL goal is the level of a particular contaminant found in drinking water below which there is no known or expected risk to health. These goals are based upon numerous scientific studies and are designed to include a margin of health safety.
- 3) Legislating enforceable standards. The EPA determines the MCL, which is the maximal permissible level of a particular contaminant in drinking water that will be delivered to all subscribers of an individual public water supply system. These levels are enforceable standards under the law and are established as close to the MCL goals as is feasible under the prevailing conditions. The SDWA defines *feasible* as the level that can be achieved using the best technology, treatment techniques, and other means at a cost of attaining those goals that EPA considers available and reasonable. If it is not economically or technically feasible to set a maximal level, or if there are no reliable or economic methods to detect contaminants in the water at the required levels, the EPA instead sets a required treatment technique that specifies a required method of treating the water to remove contaminants.

The water quality standards established through the SDWA are now in effect throughout the United States. The passage of this important bill ensures that all Americans who have public water supplies have clean water. As increasing numbers of Americans switch from well water to public water supplies and as SDWA is applied to smaller public water supplies, more people will be under the protection of SDWA. In the long term, it will promote a healthier population and reduce outbreaks of disease.

See also LANDFILLS; LEAD; PESTICIDES; UNDERGROUND STORAGE TANK; WATER POLLUTION; WELLS.

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**saltwater incursion** A very important problem for the majority of coastal communities around the world is saltwater incursion. The problem in these areas is that freshwater needed for survival meets unpotable salt water of the oceans. The salt water, by virtue of its saturation with heavy ions, is denser than freshwater and infiltrates the deeper aquifers. Freshwater is mainly introduced by precipitation and to a lesser extent by streams and rivers. Both because it is less dense and because it is introduced to the surface, freshwater fills surface pools and the shallow aquifer. The freshwater forms a wedge thinning to nothing as it approaches the shore and thickening inland. It sits atop the salt water that forms the entire deeper water supply. Unless water is piped in, shore residents must rely on the shallow water wedge for their drinking water supply.

The water supply in these areas is highly sensitive. Any substance released to the surface quickly percolates into the groundwater because of the high permeability of the sandy soils of coastal areas. Seemingly inconsequential activities such as lawn care and gardening (herbicides, pesticides, and fertilizer) can actually damage the water quality as much as most chemical spills because of the relatively huge volume of application. This sensitivity of the water supply may be the reason that these areas typically have a much higher cancer rate than inland communities.

### WELLS AND WATER USE

Residential and community wells in coastal areas must be shallow. They attempt to siphon the freshwater off the saltwater. If pumping wells draw too hard, they will cause a cone of depression in the water table. As with most cones of depression, if the well draws water faster than it can be replaced, it may go dry. Shallow wells are more prone to running dry than deep wells because there is less water available. Another problem is also encountered in coastal areas. Pumping wells may draw the salt water–freshwater interface upward toward the well bore as the freshwater is removed. If the draw is too strong, this interface may rise up to the well, which may start pumping salt water. Not only can the water not be used until the interface returns to a lower elevation than the bottom of the well, but many household items that could be damaged may be exposed to salt water.

In relatively densely populated coastal communities where there are numerous residential wells,

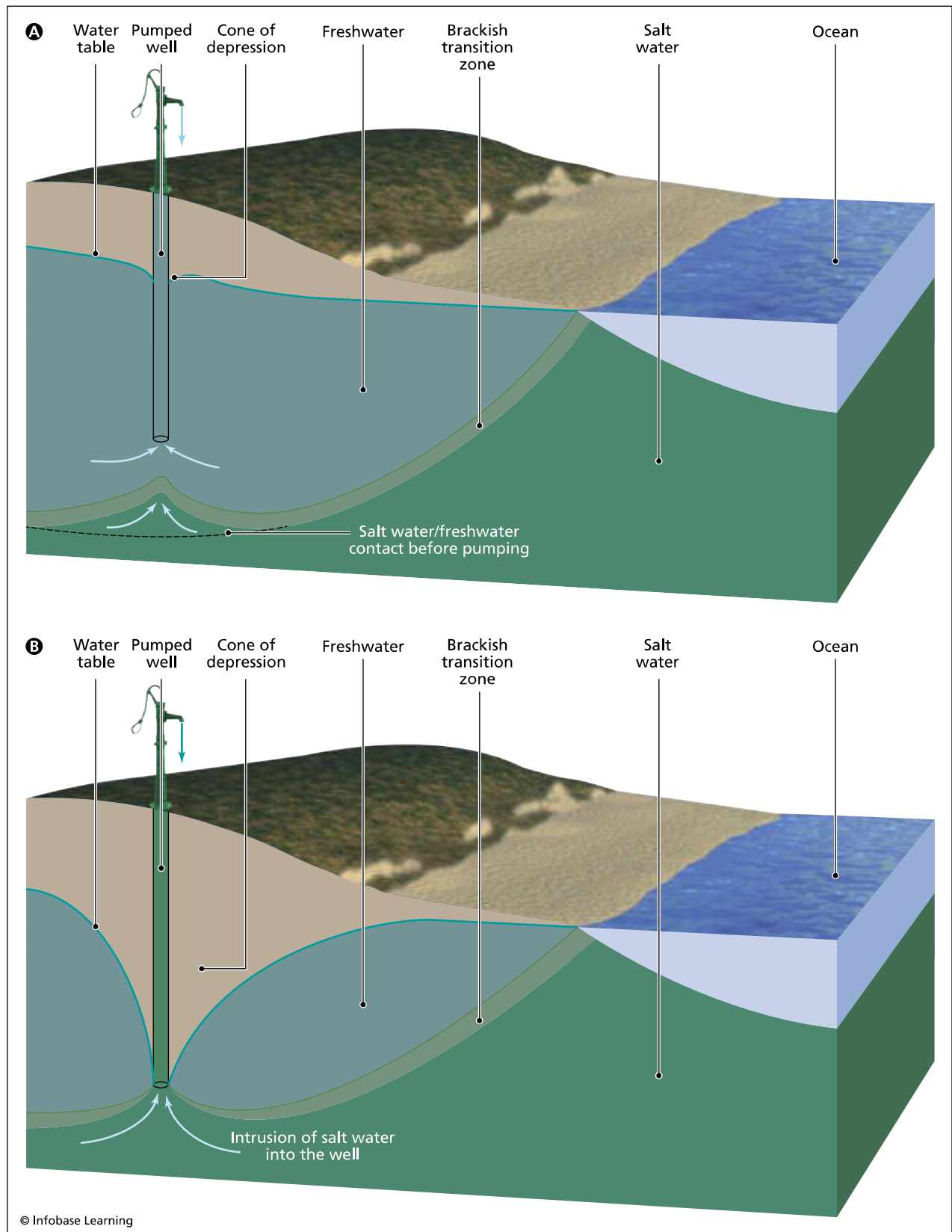
a more serious problem may arise. The freshwater wedge is generally limited in size and is commonly only replenished by precipitation. If the community draws too heavily on the wedge, it may shrink in size and volume. Instead of reaching nearly to the coast, the thin edge may withdraw far inland so that there is no freshwater at all beneath the houses closest to the beach. In some areas, this could make some houses uninhabitable. The number of houses potentially affected by saltwater incursion depends upon the density of housing and water demand of the community away from the shore.

Saltwater incursion creates particular problems in coastal communities of the highly populated East Coast. Long Island, New York; the New Jersey shore; and the Maryland shore have several areas where it has become a significant problem. Other areas, in California, Texas, and Florida, have also reported the same problem. It is for this reason that many coastal communities have switched to piping in freshwater from nearby rivers and only using their groundwater supply to supplement the drinking water supply during heavy use periods. This practice has reduced the stress on the freshwater wedge, but increased coastal building can easily overwhelm the fragile system.

See also AQUIFER; BEACHES; COASTAL PLAIN DEPOSITS.

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**Block diagrams showing two potential problems with pumping groundwater wells in coastal regions:** Lighter freshwater from precipitation sits above denser salt water from the ocean at the shore, but a pumping well may draw up the saltwater interface into the well (A); and in addition to drawing salt water up into the well, a pumping well may form a cone of depression in the water table that makes the well go dry (B).



**Santa Barbara oil spill** *Santa Barbara Channel, California (January 28–February 8, 1969)* *Water Pollution* If there is a directory of seminal events that formed America's environmental consciousness, the 1969 Santa Barbara oil spill would certainly be near the top. The daily images of the Santa Barbara oil spill on the evening news mobilized the nation and led to some of the most far-reaching opinion and public policy changes since the Great Depression.

### BACKGROUND

Along the coastline of Santa Barbara County, California, there are two east-west-oriented geologic basins, formed over millions of years of plate tectonic movements and changes in sea level related to glaciation and climate change. Both the Santa Maria Basin, which is 150 miles (241.4 km) long by 10–50 miles (16.1–80.5 km) wide, and the Santa Barbara–Ventura Basin at 185 miles (297.7 km) long and approximately 55 miles (88.5 km) wide, host large reserves of medium- to heavy-grade crude oil, as well as significant quantities of natural gas. The Santa Maria Basin contains up to 500 million barrels (79,500 million L) of petroleum and billions of cubic feet of natural gas.

Union Oil of California drilled a 3,500-foot- (1.1-km-) deep oil production well from an offshore platform named Alpha, into the heart of the Santa Maria Basin. During drilling, steel casing is used to brace the open hole and to prevent surrounding sediments from filling it in. Eventually, the steel casing is seated, or driven deep into the bedrock, to form a tight seal between the top of the borehole and the bottom of the seafloor. Union Oil received a variance from the U.S. Geological Survey to seat the bottom of the steel casing at a depth much shallower than allowed by California state regulations. The Alpha platform was 5.5 miles (8.8 km) offshore, well outside California's three-mile (4.8-km) coastal zone, and did not have to comply with state standards, which were much stricter and more expensive than those of the federal government.

Oil, gas, and water present deep below ground in the rocks of the Santa Maria Basin are under tremendous pressure. To prevent the sudden, uncontrolled rush to the surface of these materials during drilling called a blowout, drilling mud is pumped into the borehole. This mud is kept at the same pressure as the oil, gas, or water in the geologic formation being tapped and forms an effective barrier to their release, thus helping to prevent blowouts.

### THE OIL SPILL

During the morning of January 28, 1969, workers removed a section of pipe from the borehole to replace

a broken drill bit on platform Alpha. They had not pumped enough mud into the borehole to compensate for the loss of volume caused by the removal of the drill pipe. This allowed a sudden increase of pressure to occur inside the borehole. This increase in pressure split the upper part of the steel casing, which, because of the variance, had not been installed deeply enough into the bedrock to provide adequate support. As a result, not only was the integrity of the well casing destroyed, but so was the bedrock that formed the seafloor. The rock was fractured in five places around the well. Oil and gas burst through the split casing, and broken bedrock of the seafloor and began to pour into the sea. A blowout had occurred, and, over the next 11 days, approximately 3 million gallons (11.4 million L) of oil flowed into the Pacific Ocean and was pushed by wind and currents into the pristine and biologically diverse waters of Santa Barbara's beaches, harbors, and channels.

The 800-mile- (1,288-km-) long slick tarred 35 miles (56 km) of beaches from Rincon Point to Goleta. Eventually shorelines as far south as Ana-



**Oil on Hobson Beach, Santa Barbara, California, after the blowout at Union Oil Company's undersea drilling platform several miles offshore, February 1969** (Vernon Merritt III/Time & Life Pictures/Getty Images)

capa Island's Frenchy's Cove, Santa Cruz, Santa Rosa, and the San Miguel islands were affected. Oil clogged the blowholes of dolphins, causing lung hemorrhages, and animals that ingested the oil, including more than 4,000 seabirds and an unknown number of seals, were poisoned. The bodies of the dead birds washed onto the shore for months after the blowout had been controlled.

### THE CLEANUP

Skimmer ships scrambled to collect the oil, while airplanes sprayed detergents (dispersants) on the surface of the water to break up the slick. Closer to shore, straw was used to absorb oil from isolated harbors and estuaries, and rocks were steam cleaned. This effort had the unfortunate side effect of parboiling the limpets and mussels attached to them. The dispersants used to break up the oil were found later to be almost as poisonous to birds and other marine life as the oil.

To control the blowout at the shattered well, drilling mud was pumped into the ruined steel casing at the rate of more than 60,000 gallons (227,125 L) per hour. After almost two weeks of round-the-clock work, the flow of oil was finally cut off and the well sealed with a thick cement plug. Residual amounts of oil and gas continued to escape from the cracks in the seafloor, and over the ensuing months all of the fractures were sealed with mud.

### THE AFTERMATH

The cleanup, payments to fishermen and local businesses, and lawsuit settlements cost Union Oil and its insurers several millions of dollars and forever changed the attitude of Californians about the wisdom of offshore oil exploration. The consequences of the Santa Barbara oil spill, however, spread far beyond California and changed the opinions of the nation.

Gaylord Nelson, a Democratic senator from Wisconsin, who was in California when the blowout occurred, toured the fouled beaches. He was so affected that he organized the first Earth Day the following year to raise public awareness of the human connection to the environment. A ban was placed on drilling for oil off the coasts of the United States. It lasted almost 20 years, and even today the exploration and development of potential offshore oil reserves on both the West and East Coasts meet with opposition, especially in California. Currently, there are only about 10 drilling platforms actively extracting the last of the oil from the known reserves in the Santa Maria and Santa Barbara–Ventura Basins. Although there were sales in the late 1990s

of offshore federal leaseholds to allow for additional exploration, the major oil companies have not shown much enthusiasm for pursuing their development.

Sensing the country's mood after the Santa Barbara oil spill, President Nixon signed the National Environmental Policy Act of 1969, which paved the way for the July 1970 establishment of the U.S. Environmental Protection Agency (EPA). Not surprisingly, federal and state regulations governing oil drilling procedures were toughened. In 1970, *Time* magazine called environmental quality the “issue of the year,” and a Gallup poll found that almost 70 percent of the American people considered air and water pollution to be serious problems. By 1972, the Clean Water Act and Clean Air Acts had been passed, and it became clear that environmentalism had established itself as a legitimate public policy issue.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS.

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**Savannah River Site Eastern South Carolina–Georgiaborder (1952–present) Water and Soil Pollution** In the 1950s, as part of the effort by the United States to develop and maintain its nuclear arsenal, a facility was built to purify and fabricate plutonium and tritium, some of the most technically challenging and dangerous work involved in the process. The Atomic Energy Commission (predecessor of the Department of Energy [DOE]) purchased 300

square miles (770 km<sup>2</sup>) of sparsely populated forest and swampland about 20 miles (32 km) southeast of Aiken, South Carolina, along the Savannah River, which separates Georgia from South Carolina. The Savannah River Site (SRS) is a secured, highly guarded facility with no permanent residents or housing facilities. The site is owned by the DOE and operated by a consortium of government contractors. There are about 16,000 employees at SRS and the annual budget is about \$1.5 billion.

### SRS FACILITIES

The SRS mission through the end of the cold war in about 1990 was to receive, store, and manufacture tritium and plutonium 239, the basic materials used in the assembly of nuclear weapons. More recently, SRS has refocused its activities to include the development and implementation of waste management solutions for the hazardous and nuclear residues present on the site. SRS is a massive industrial and research complex whose operations have left a legacy of severe environmental issues, and the DOE and its contractors are working aggressively to address them. There are numerous facilities that have these problems.

### POLLUTION AND REMEDIATION OF THE SITE

The primary constituents of concern released into the SRS environment are tritium, lead, trichloroethylene (TCE), and uranium. More than 500 waste units that require investigation, remediation, and closure in order to reduce risk and protect human health and the environment have been identified at SRS. These activities are being carried out under a variety of federal and state programs including CERCLA, RCRA, a Federal Facility Agreement (FFA), and a triparty agreement of the U.S. Environmental Protection Agency (EPA), the South Carolina Department of Health and Environmental Control, and the DOE. By 2005, SRS had closed almost 330 waste units, with another 48 units undergoing active remediation.

SRS operations contaminated groundwater around 15 waste disposal facilities. Extensive monitoring and remediation programs are tracking and cleaning up the contamination. No off-site wells have been contaminated by the migration of SRS groundwater. Although the Savannah River is used as a drinking water supply source for some residents downriver of SRS, the nearest intake is approximately 90 miles (145 km) downriver of the site. The river is also used for commercial and sport fishing, boating, and other recreational activities, but there are no known large-scale uses of the river



**Nuclear production facilities at Savannah River Site, Aiken, South Carolina, 2004** (DOE Photo)

for irrigation downstream of the facility. Groundwater remediation includes proper closure of waste sites to isolate them from the hydrogeologic environment and reduce the migration of contaminants into groundwater, as well as active recovery and treatment of contaminated water.

SRS is using a technique known as intrinsic bioremediation (also called monitored natural attenuation [MNA]) to address about 3,000 acres (1,214 ha) of wetlands, lake beds, and canals that have been contaminated with Cs-137 from discharges of reactor cooling water. The extremely large affected area makes removal of the contaminated soil impractical. Other types of remedial methods (e.g., stabilization or grouting) would essentially destroy a highly functioning wetland.

MNA is one of the more controversial approaches to site remediation. The EPA describes it as reliance on natural processes that, under favorable conditions, operate without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in the soil. These natural processes include not only biodegradation, which is the most important, but also a variety of other physiochemical processes, which include dispersion, dilution, sorption, and volatilization. Critics regard MNA as a no-action approach. For MNA to be effective, three conditions must be met at a site:

- The source of the contamination must be under control. MNA processes can be quickly overwhelmed by the continued influx of additional contaminant. The leaking tank or pipeline must be repaired or decommissioned and subsurface nonaqueous-phase liquid (NAPL) removed in order to give the relatively slow-acting biodegradation time to process the released material.



- Suitable microorganisms need to be present in sufficient quantities in the soil to degrade the contaminant. Given the ubiquitous nature of bacteria and their highly adaptive character, this is usually not a problem.
- Necessary electron acceptors and nutrients must be present in large enough amounts to allow the establishment and maintenance of a bacterial population that can degrade the contamination. This is why most sites

### POLLUTED AREAS AT THE SAVANNAH RIVER SITE

Facility	Description
Burial Grounds	A 200-acre (81-ha) area operated between 1952 and 1995 that is currently undergoing investigation and remedial plan development as part of the CERCLA program.
Consolidated Incinerator Facility	A 40,000-square-foot (3,716-m <sup>2</sup> ) incinerator was constructed in 1995 to incinerate low-level radioactive, hazardous, and mixed wastes safely.
Defense Waste Processing Facility (DWPF)	A 42,000-square-foot (3,902-m <sup>2</sup> ) structure that receives, treats, and immobilizes alkaline slurries of aqueous high-level waste into a durable, nonleachable borosilicate glass for disposal in a geological repository. Sixty-four canisters of vitrified high-level waste were processed successfully by this facility in 1996.
E-Area Vaults	These vaults, placed into service in 1994, cover approximately 100 acres (40 ha) and are used for the disposal of solid and low-level radioactive waste.
F Canyon	A 128,000-square-foot (11,892-m <sup>2</sup> ) facility used for the separation of plutonium and uranium and processing of plutonium and other materials. DOE is slowly decommissioning F Canyon.
FB Line	A 55,000-square-foot (5,110-m <sup>2</sup> ) plutonium separation facility constructed in 1953. Plutonium is currently stored in this building, awaiting stabilization prior to final disposal.
H Canyon and H Canyon Outside Facility*	A 403,000-square-foot (37,440-m <sup>2</sup> ) facility used for the separation of plutonium. This building will be used in processing of unneeded reactor fuels and in the purification of Pu-238 and other radioactive isotopes.
HB Line	A 28,000-square-foot (2,601-m <sup>2</sup> ) plutonium processing facility constructed in the 1980s and currently used for the storage of Pu-238 oxide product and scrap material. In 1991, five workers were contaminated by HB Line operations because of inadequate safety procedures. Operations resumed in January 1993 after extensive safety reviews caused by this and several other incidents.
In-Tank Processing Facility (ITP)	A 5,000-square-foot (465-m <sup>2</sup> ) nuclear waste processing facility intended to process high-level radioactive wastes and produce a decontaminated salt solution that is only slightly radioactive. This solution is processed further for disposal in the Saltstone facility.
Liquid Waste Handling Facilities	These facilities receive and store liquid radioactive waste, prepare the waste for processing, and transfer the prepared waste to DWPF and Saltstone for processing into stable, inert solids. SRS wastewater effluent also is treated within this operational center.
M Area Fabrication Facilities	These facilities are being used to decommission reactor materials in a safe, environmentally sound manner and to treat previously generated mixed low-level waste.
Naval Fuels	A 110,000-square-foot (10,291-m <sup>2</sup> ) enriched uranium fuel manufacturing facility that was constructed in 1987. This facility is currently not operational and is in a surveillance and maintenance mode. Process facilities are inactive and contain residual nuclear material resulting from previous operations. Procedures to shut down the facility have not yet been developed.
Old HB Line	A Pu-238 processing facility that was terminated in 1984. It produced Pu-238 oxide primarily for the space program as a heat source to be used in generating electricity for spacecraft in deep space. The new HB Line replaced it in 1984. In 1988, during decontamination activities related to decommissioning, four workers became contaminated during an emergency exiting of a highly contaminated area. This was due to the failure of a breathing-air compressor.

(continues)



**POLLUTED AREAS AT THE SAVANNAH RIVER SITE** *(continued)*

Facility	Description
PUFF	A 55,000-square-foot (5,110-m <sup>2</sup> ) facility containing Pu-238 hot cells that are currently in cold standby and serve as a storage area for nuclear material from weapons and nonweapon production.
Reactors (K, L, P, C, and R)	These are five heavy water nuclear materials production reactors that were used to generate plutonium, tritium, and miscellaneous isotopes. The K and L Reactors were used primarily for tritium production but are in safe shutdown mode. The P, C, and R Reactor facilities generated tritium as their primary mission but are currently used for isotope storage. They are in cold shutdown with no capability for restart.
Receiving Basin for Off-site Fuel	This is an operationally active spent fuel storage for research reactor fuels. It receives, handles, and stores irradiated nuclear fuel from off-site power and research reactors, from foreign reactors, and from on-site reactors. These materials are repackaged into containers and bundles for extended storage and/or shipment to on-site or off-site reprocessing facilities. This facility supports the SRS's technical role in controlling nuclear proliferation.
Saltstone	Includes the operations building and two concrete disposal vaults that are used to immobilize and dispose of decontaminated salt solutions. These solutions contain low-level radioactive compounds and heavy metal ions and are immobilized by mixing them with fly ash, cement, and slag. The slurry then is poured into large concrete vaults to harden. These vaults are the permanent disposal sites for the neutralized waste material.
Solid Waste Management Facility (SWMF)	The facility stores transuranic wastes, mixed wastes, and nonradioactive hazardous waste materials. It also disposes of low-level solid radioactive wastes generated from production of nuclear materials. It is made up of a series of burial grounds, vaults, and storage pads.
Storage of High-Level Radioactive Wastes	Tank farms at SRS store approximately 35 million gallons (132.5 million L) of liquid waste, constituting more than one-half (533 million ci) of DOE's high-level radioactive inventory. Unless properly managed, these wastes can pose radiological and environmental risks. The tank farm facilities consist of 51 USTs with a capacity of about 1 million gallons (3.8 million L) each. Two evaporators are used to concentrate the waste, and transfer pipelines, diversion boxes, pump pits, and associated vessels and pumps safely manage and transfer the tank contents. As tank contents are processed, low-level radioactive residues are sent to Saltstone, and high-level wastes are vitrified at DWPF for eventual shipment off-site.
Transuranic Waste Storage Pads	Nineteen storage pads occupying 114,000 square feet (10,591 m <sup>2</sup> ) have been in use since 1974. The containers on some pads are covered with soil, whereas others have weather-resistant enclosures. Eventually, the material on this pad will be assessed to determine whether it can be disposed of directly or treatment is necessary prior to disposal.
Tritium Facilities	These facilities provided tritium processing capabilities necessary for both nuclear weapons production and nonweapon (medical, research, etc.) uses. Three buildings make up this area, and they were used for such operations as extraction and purification, loading and unloading, and shipping and receiving.

**NOTES**

\* The building is called a canyon because of its long rectangular shape and hardened structure. Work inside the building is performed remotely, and employees are not exposed to radiation because of thick concrete walls.

fail. Bacteria quickly use up the oxygen, nitrogen, and other electron acceptors present in the subsurface, and biodegradation slows or stops until these materials are replenished. Even though other MNA pro-

cesses (dilution, dispersion, volatilization) can continue to operate, the time frames to reach cleanup goals may be unacceptably long without actively operating biodegradative processes.

An aggressive and comprehensive monitoring plan must be implemented at sites where MNA is the proposed remedial solution, and MNA processes must be periodically evaluated. This type of monitoring will alert the responsible party and regulatory agencies if hydrogeologic or geochemical conditions change to inhibit or adversely affect ongoing remedial processes.

### THE MNA SOLUTION

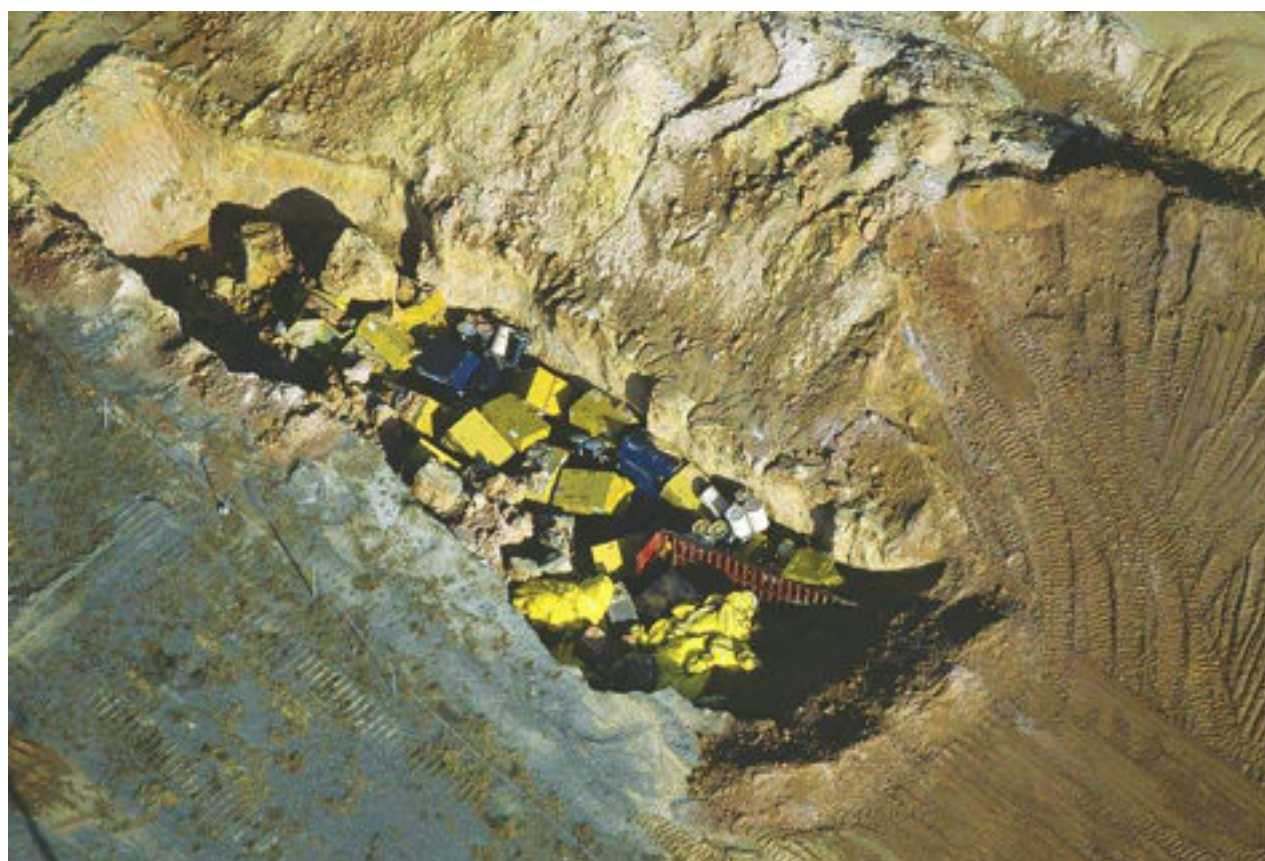
As a practical matter, most sites do not contain the necessary nutrients and electron acceptors in sufficient quantities to allow native bacterial populations to degrade the contaminants. Once more active remedial processes are under way, MNA may be appropriate for the outer edges of the plume or residual amounts of contamination.

Regulatory agencies and the public are justifiably suspicious when a responsible party presents a plan for an MNA-based remedy. To win acceptance for this type of approach, the responsible party must demonstrate a thorough understanding of site hydrogeology, biology, and geochemistry. The use of institutional property controls (zoning and land

use restrictions) may be necessary to ensure that land use at the site does not change in a manner that disrupts MNA processes or creates an unacceptable public health or environmental risk.

MNA is most frequently used at sites where soil or groundwater has been contaminated with pesticides, chlorinated solvents, gasoline, or polycyclic aromatic hydrocarbons (PAHs). MNA, however, works well on radionuclides. The decay of radionuclides is predictable and not subject to the availability of electron acceptors. All that is required is that the source is under control (i.e., no more releases are occurring) and that the radionuclides are not migrating. This is why MNA is being used in the wetlands at SRS.

Although the sediments present in the SRS wetlands contain some clay, not enough is present to ensure that the cesium will bind to that material and be less likely to migrate. The remedial engineers at SRS plan to seed the lake bottoms, wetlands, and former discharge canals with illite to help bind the cesium and prevent its migration or movement into the ecosystem. After placement of the illite, the area will be monitored while the cesium, which has a half-life of 30 years, slowly decays to levels that are not harmful to public health or the environment.



Burial of low-level radioactive solid waste at Savannah River Site, South Carolina, ca. 2001 (Peter Essick/Aurora Photos)

While MNA is an attractive remedial option, its use must be carefully considered. Time frames to achieve cleanup goals will be longer than for those of more active remedial measures. Long-term monitoring is necessary to ensure that contaminants are not moving because of changes to local geochemistry that may occur seasonally or over longer time frames. Institutional controls (restrictions on current and future land uses) are typically required components of an MNA plan along with the need for an extensive education and outreach program to gain public acceptance.

See also BIOREMEDIATION; IN SITU GROUNDWATER REMEDIATION; LEAD; RADIOACTIVE WASTE; TCE.

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**Sea Empress oil spill Milford Haven, Wales (February 15, 1996)** *Water Pollution* One way oil is classified or graded is by the location where it occurs (e.g., West Texas or the North Sea), but the physical and chemical properties such as sulfur content, viscosity (resistance to flow), and specific gravity are used as well. "Sweet" oil usually is oil that contains very little sulfur. "Sour" oil, or gas is relatively high in hydrogen sulfide and requires additional refin-

ing to remove this undesirable constituent. "Light" oil has a low wax or paraffin concentration (long-chain alkane hydrocarbons) and can be pumped readily into tankers or pipelines. "Heavy" oil has a higher wax concentration and is more difficult to process and handle. Wax content is measured indirectly by evaluating the viscosity of the oil. A trade association called the American Petroleum Institute (API) has developed standardized methods to determine oil viscosity, which is a measure of specific gravity, or the weight of oil in comparison to water. Light crude oils have high API gravities. These types of oils tend to yield greater amounts of gasoline and require less refining than heavier oil. Oil that is sold as "West Texas Light Sweet crude" provides a frame of reference or benchmark price for brokers and companies that buy or market oil with similar characteristics from other parts of the world.

"North Sea Brent" oil is extracted from a number of fields in the North Sea and has long served as the benchmark against which the price for other grades of oil from this area and certain types of similar oils from Africa and the Middle East is set. As the supply of oil from the Brent fields began to decrease in the early 1990s, producers recognized the need to establish a new benchmark. "Forties Blend" gradually became an alternate benchmark oil replacing North Sea Brent. Forties Blend is a crude oil made up of both oil and gas liquids from 20 fields in the central part of the North Sea oil production zone. It is light oil (low viscosity) with a high percentage of volatile compounds and has an American Petroleum Industry (API) weight (specific gravity) of 40°. Forties Blend is also low-sulfur oil, generally containing about 0.35 percent sulfur or less.

### BACKGROUND

Much of the oil extracted from the sediments under the North Sea is pumped into supertankers and transported to Milford Haven, a port on the Pembrokeshire coast of Southwest Wales, United Kingdom. Almost the entire 170-mile- (273.6-km-) long coastline in this area is included in the Pembrokeshire Coast National Park, an important habitat for seabirds. The numerous and well-developed coves and estuaries along this coastline also serve as breeding grounds for a thriving marine fishery and support an extensive and diverse land and sea mammal population. Essential to the local economy, Milford Haven is a large natural harbor carved out of the rocky coastline by the confluence of several major rivers that drain into the sea. Milford Haven is the United Kingdom's major oil port and its fourth busiest port overall. Widely used by oil tankers, fer-



ries, the locally based commercial fishing fleet, as well as private pleasure craft, Milford Haven has a petroleum handling and processing infrastructure that recently underwent a \$4 billion expansion to increase its natural gas-handling capacity.

It was into this economically vital and exceptionally beautiful area that, in February 1996, the Liberian-owned and Russian-crewed *Sea Empress* steamed, fully loaded with 143,300 tons (130,000 metric tons) of Forties Blend oil. Built in Spain in 1993 as a single-hull Suezmax crude oil carrier, it was 900 feet (274.3 m) long, with a beam of 142 feet (43.2 m). Fully loaded, it could travel at almost 14 knots (26 km/h) powered by a 45,000-horsepower, No. 6 oil-fired engine driving a single screw. When the vessel arrived off Milford Haven, the Convention, Flag State (Liberia), and Class certificates were valid and up-to-date. Only three years old, the *Sea Empress* was in good mechanical condition. It had loaded the cargo at Hound Point, in the Firth of Forth (an offshore tanker loading and berthing facility in Scotland), and arrived about three miles (4.8 km) from the entrance to Milford Haven harbor on Thursday, February 15, 1996, just after 7:00 P.M.

### THE ACCIDENT AND SPILL

As required by most maritime regulations, a harbor pilot boarded the *Sea Empress* a few minutes after 7:00 P.M. to guide the ship the rest of the way through the harbor to its dock at a Texaco oil terminal. The weather was clear, with a stiff (10–20 mph [16–32 km/h]) west-northwesterly wind. The tide was retreating (ebbing), and there was a need to move the ship quickly to its berthing point so unloading could begin that evening. Water levels in the harbor would reach their lowest levels at around 9:30 P.M. Although the harbor pilot navigated the ship, the *Sea Empress* was still under the command of its captain, and, at about 7:45 P.M., the harbor pilot began directing the vessel toward the main entrance channel. Each course correction and speed requested by the harbor pilot was repeated to the helmsman and bridge crew in both English and Russian by the captain, whose command of these languages was later reported to be excellent. Unlike in the *Braer*, the level of effective communication between officers and crew was very good.

Commercial shipping into Milford Haven harbor is directed northward into one of two channels: the East Channel, which is the shallower of the two at about 30 feet (9.8 m), and the much deeper, although more narrow West Channel, with an average depth of about 50 feet (16.5 m). Because the draft of the fully loaded *Sea Empress* (i.e., the depth of the keel

below the water line) was just about 50 feet (17 m), the harbor pilot directed the ship toward the West Channel. The depth of the West Channel is maintained by regular dredging, an expensive and time-consuming process, so its approximately 1,200-foot (370-m) width is designed barely to accommodate the simultaneous passage (in opposite directions) of two very large crude carriers (VLCCs) such as the *Sea Empress*. The limits of the channel are marked by two buoys, Saint Ann's Light Buoy on the port (left) side, and Mid Channel Rocks Light Buoy, on the starboard (right) side. Fixed shoreline lights and buoys also are present to help direct ships to the midpoint or deepest part of the channel. The north-northeast-oriented West Channel is bounded on its western side by St. Ann's Head Shoals, where the sandy bottom of the channel is quite shallow. To the east of West Channel are the Middle Channel Rocks, an area where submerged boulders and shallow bed-rock form a hazard to navigation.

As the *Sea Empress* entered West Channel, the harbor pilot knew to keep the ship near the center of the waterway but had to include in his navigational plan the effects of the northwesterly wind, an outgoing southerly tide, and possibly an easterly cross-tide from St. Ann's Head that sometimes flowed at right angles to the point of approach. Requesting that the *Sea Empress's* speed be increased to its 14-knot (26-km/h) maneuvering pace, the harbor pilot could see the vessel was correctly aligned to enter the West Channel, about one mile (1.6 km) out. Adjusting the course slightly to the west, to account for the eastward-flowing tide, the *Sea Empress* was making 10 knots (18.5 km/h), and the harbor pilot, bridge crew, and captain thought all was going well. As the West Channel marker lights came into view about 1,500 feet (457 m) from its starting point, the harbor pilot realized that he had not corrected the course enough to account for the eastward-flowing tide and that the *Sea Empress* had been pushed east of the channel. He requested another course correction, but the ship responded too slowly, and, as the lights marking the Middle Channel Rocks passed by on the starboard side, a shuddering vibration ran throughout the ship, and then a popping sound was heard from below decks, accompanied by a strong smell of oil. At this same time, the helmsman reported that the vessel was not steering. The harbor pilot requested "full astern" and the captain ordered that both anchors be let go. He then radioed to request assistance from the four harbor tugs that had been standing by to help push the *Sea Empress* into its berth at Milford Haven.

The *Sea Empress* went aground near the southern entrance to the West Channel in an area known as



“the Pool.” This is a half-mile- (804-m-) wide, half-mile- (804-m-) long, 60-foot- (18-m-) deep section of the harbor that resembles the top of a funnel, with the West Channel forming the neck as it extends northward toward Milford Haven. Over the next three days, the *Sea Empress* bounced around the Pool like a pinball, pushed by gale-force winds, waves, currents, and tides, as tugs and salvage teams tried desperately to secure the vessel and unload its cargo.

Three cargo tanks and two ballast tanks on the *Sea Empress*’s starboard side had been breached when the ship skidded into the Middle Channel Rocks. It was listing 10 degrees to starboard and the pump room, the part of the ship where the cargo tank unloading controls were located, had flooded. By 4:30 A.M., it had been towed into the center of the Pool, the anchors reset, and four tugs were holding it steady. Another tanker pulled alongside to begin transfer of the *Sea Empress*’s cargo, and a salvage team was attempting to regain access to the pump room so that process could begin.

Weather conditions deteriorated during Friday afternoon and evening, and the tugs strained to hold the *Sea Empress* in position, even with the help of its own main engine. As the stormy weather turned into a full-fledged gale, it became increasingly more difficult to hold the *Sea Empress*’s stern toward the predominant direction of wind and waves, and port authority officials decided to turn the ship so that the bow pointed seaward. This required seven tugs, but by 4:00 P.M. Saturday, the turn was completed. The *Sea Empress*’s anchors, however, had been crossed and were now hopelessly tangled and unusable. An hour later, the *Sea Empress* began to move westward, pushed by the outgoing tide and a 40-knot (74-km/h) wind. The tugs tried valiantly to prevent the ship from drifting, but two towlines separated, and, despite its own engine’s straining, the *Sea Empress* went aground again, this time against the shoals off St. Ann’s Head. More tugs were called, and the salvage team decided to try to stabilize the *Sea Empress* on the shoal by flooding the undamaged ballast tanks. Those onboard were evacuated as wind speed increased to 60 knots (111 km/h) and two more tugs arrived on scene to attempt to hold the *Sea Empress* in place on the shoal by the bow. At 8:00 A.M. Sunday morning, however, the *Sea Empress* floated off the shoal on a rising tide and drifted eastward, smashing again into the Middle Channel Rocks. Forty minutes later, *Sea Empress* was on the move once more, this time coming to rest about 1.5 miles (2.4 km) northeast of the Middle Channel Rocks light, finally clear of the West Channel and at the northeast end of the Pool. At daylight, it drifted again, this time toward the

Middle Channel Rocks, and on early Monday, the ship went aground there at around 8:00 A.M. Salvage crews boarded the derelict to assess the damage and once again clear the pump room so that lightering could begin. At this point, the *Sea Empress* still held 132,000 tons (120,000 metric tons) of oil.

Later that afternoon (Monday), *Sea Empress* refloated and, taking five tugs along, moved westward across the main channel and went aground at St. Ann’s Head shortly after 6:00 P.M. Hearing noises that suggested a hull failure, the salvage crews were evacuated. The next morning, with *Sea Empress* having spent a rough night bumping and grinding against the shoal, salvage personnel and tugboat crews reported a significant amount of oil present in the water around the vessel.

Over the next 24 hours, salvage crews succeeded in gaining access to the pump room and were able to empty several of the ballast tanks to level off the badly listing ship. This, combined with the oil it was leaking, improving weather, and the use of 13 tugboats, allowed *Sea Empress* to be refloated at 6:00 P.M. on Wednesday evening and to be secured to a berth with mooring lines alongside Herbrandston Jetty just before 10:00 P.M. It had lost almost 79,000 tons (72,000 metric tons) of oil during the six-day ordeal into North Haven, more than half of the cargo. The North Sea Forties Blend oil that the *Sea Empress* was carrying is lightweight and volatile, oil that is more readily degraded by natural environmental processes (wind, waves, evaporation) than other types of oil. Despite the relative environmental friendliness of the oil, and even though the spill occurred in the dead of winter when habitat usage was low, the environmental consequences of the spill were still significant.

## AFTERMATH

More than 120 miles (200 km) of coastline was polluted, and of the 12,000 birds thought to have been present in nearby Pembrokeshire Coast National Park at the time of the disaster, up to 4,000 may have died and another 5,000 coated with oil. A ban on commercial fishing and shellfish collection, critically important to the local economy, was established by health authorities and extended over some 810 square miles (2,100 km<sup>2</sup>). Spawning rates for sea bass, the main commercial fish taken from the waters in and around North Haven, declined dramatically in 1996. Tourism, a \$300-million industry, was not affected very adversely, thanks in part to the more than 1,000 volunteers and workers who worked diligently for more than six weeks to remove more than 16,500 tons (15,000 metric tons) of emul-

sified oil and debris from accessible beaches and coves. Of the remaining oil, 40 percent evaporated or was blown out to sea by the same winds that had helped push *Sea Empress* around the North Haven Pool. About 2 percent of the oil was recovered by mechanical skimmers and booms, and almost 50 percent of it was degraded either by natural dispersion or aerially applied chemical dispersants. Only about 5 percent or so of the oil, 4,400–5,500 tons (4,000–5,000 metric tons), is thought to have washed up on beaches. Eighteen months after the spill, most coastlines were oil free and marine life was not showing visible signs of distress. In 2003, insurers paid out approximately \$60 million in claims, as compensation to local residents, for spill cleanup costs, and as compensation to Texaco for the value of the cargo.

The subsequent government inquiry into the cause of the wreck concluded that it was the harbor pilot's error in failing to correct adequately for the eastward-flowing tidal current present near the entrance to the West Channel. This error was, in part, related to inadequate training and a lack of a thorough understanding of current and tidal patterns within the channel. Since the *Sea Empress* oil spill, harbor pilot training regimens have improved and a comprehensive mapping and charting of harbor, channel, and Pool tidal patterns has been undertaken.

See also BEACHES; BRAER OIL SPILL; OIL SPILLS; TIDES; TORREY CANYON OIL SPILL; WATER POLLUTION.

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**selenium** Like many of the inorganic contaminants, selenium is a necessary nutrient in very small quantities but a dangerous health hazard at high levels. Selenium may be the most paradoxical of all of the elements that display this relation in that a little is believed to prevent cancer whereas a lot (in another compound) causes it. For this reason, there are recommendations from the Food and Drug Administration that a minimal amount of selenium should be ingested by all people, and regulations by the U.S. Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), and the National Institute of Occupational Safety and Health (NIOSH) against excessive exposure. The lack of selenium has been tied to strokes in humans and "white muscle disease" in sheep. There are several cities in China, however, where the level of naturally occurring selenium is so high that residents suffer from selenosis. Selenium has been ranked as the 147th worst environmental threat of the 275 chemicals on the 2007 CERCLA Priority List of Hazardous Substances, and it has been found in 508 of the first 1,636 EPA-designated Superfund sites (National Priorities List) where it was tested. Although selenium does not commonly occur in high quantities, it can be concentrated by both anthropogenic and natural processes.

#### PROPERTIES, USE, AND PRODUCTION

Selenium is a naturally occurring inorganic element that is present throughout the environment in very small quantities. It occurs in three forms: noncrystalline gray metal, deep red to black powder, and red crystals. Its form depends upon the valence state and compound. It can occur in the  $-2$  valence state (hydrogen selenide, sodium selenide, dimethyl selenium, trimethyl selenium, and selenoamino acids); 0, or elemental selenium;  $+4$  valence state (selenium dioxide, selenious acid, and sodium selenite); and  $+6$  valence state (selenic acid and sodium selenate). Selenium was discovered in Sweden in 1817 as a contaminant. There are no high-selenium minerals in minable quantities. Instead, it has been produced as a by-product of copper refining and, more recently, of coal processing and burning.

Early uses of selenium were in rubber compounding, steel alloying, and production of rectifiers for electrical inversion. By 1970, silicon had replaced most selenium in rectifiers, and the leading use switched to a photoconductor in copiers. In the 1980s, however, this application declined. In the 1990s, it began being added to dietary supplements, though the volume of this application is relatively low. In the late 1990s, selenium was increasingly

used in plumbing brass to meet no-lead standards. Today, about one-third of total selenium is used to remove the green tint in glass caused by impurities and in architectural plate glass to reduce solar heat transmission. Cadmium sulfoselenide pigments consume about 20 percent to produce ruby-red color in plastics, ceramics, art glass, and other glasses, such as that used in traffic lights. Selenium is used in catalysts, in plating solutions to improve appearance and durability, in blasting caps and gun bluing, in rubber compounding chemicals, in electrolytic production of manganese to increase yields, and as an additive to improve machinability of copper, lead, steel, and brass alloys. Selenium is used as a human dietary supplement and in antidandruff shampoos (Selsun Blue). It also has strong photovoltaic capabilities and is used in solar panels and solar calculators. Agricultural uses are as a dietary supplement for livestock and as a fertilizer additive to enrich selenium-poor soils. In 1985, domestic production was reported at 429,515 pounds (195,234 kg). In 2006, the United States imported about 473 tons (430 metric tons) of selenium. The sources of selenium traditionally have been Belgium, 33 percent; Canada, 31 percent; Philippines, 15 percent; Germany, 6 percent; and others 15 percent.

### ENVIRONMENTAL RELEASE AND FATE

Small amounts of selenium are naturally present in rocks and soil everywhere, making it a non-point source pollutant. Selenium may also be a point source pollutant from a number of sources. It can be released from industry that uses selenium through leaks during transport, storage, and disposal. It may also be released from copper smelting, coal burning, petroleum refining, and coal mine effluence, among other sources. Selenium may be released into the air in compounds as particles from the burning of coal and oil or from volcanic eruptions. The particles primarily fall out or are washed out by precipitation close to the source, thereby increasing soil and surface water concentrations. Depending on the form, selenium either sinks in surface water if it is insoluble or dissolves into it if it is soluble. Insoluble selenium settles into the sediment and is very stable. Similarly, if released into the soil, insoluble selenium is immobile and remains a component of the soil indefinitely. Soluble selenium is highly mobile and leaches into the groundwater system. Selenium may also be taken up by plants. In acidic soil under anoxic conditions, uptake will be low; in alkaline soils, it may be significant.

According to the EPA Toxic Release Inventory, from 1987 to 1993 more than 1 million pounds (454,546 kg) of selenium was released to the environment from industry. The releases were primarily from copper smelting to land. The state with the highest release was Utah, followed distantly by Arizona, and even more distantly by Wisconsin, Indiana, and Texas. In 2005 alone, the release of selenium and selenium compounds in on-site disposal and releases totaled 1,483,064 pounds (674,120 kg), not including injection wells or landfills.

Selenium is generally toxic to aquatic life and has been known to be devastating to fish. Further, it bioaccumulates in muscle tissue, although it is not appreciably biomagnified. It is also toxic to waterbirds, which are exposed to selenium by eating tainted aquatic organisms.

### HEALTH EFFECTS FROM EXPOSURE

Although in low doses, selenium stimulates antibody production, makes antioxidants work effectively, helps regulate ion fluxes through membranes, and aids in the synthesis of coenzyme Q, in high doses, it can be harmful to human and animal health. Acute oral exposure can produce irritability, chills, muscle aches and pains, nausea, vomiting, abdominal pain, diarrhea, excess salivation, shallow breathing, tremors and convulsions, liver malfunction, pulmonary edema, coma, and death with increasing dosage. Laboratory animals also showed symptoms of liver and spleen congestion, kidney congestion and hemorrhage, altered blood chemistry, and pulmonary congestion and hemorrhage. Inhalation of selenium dust can cause irritation of the nose and throat, coughing, nosebleeds, loss of sense of smell, bronchial spasms, bronchitis, and chemical pneumonia, among the other symptoms common to ingestion. Dust can also cause skin and eye irritation. Chronic exposure to selenium results in loss of hair and nails, clubbing of the fingers, skin lesions, tooth decay, peripheral anesthesia, pain in the extremities, hyperreflexia of the tendons, numbness, convulsions, paralysis, and motor disturbances. Laboratory animals showed loss of hair, malformed hooves, rough hair coat, impaired vision, paralysis, liver and kidney damage, and immune system damage. Selenium has also been shown to have negative effects on the reproductive system including decreased rates of conception, increased rates of fetal absorption, reduced birth weights, and birth defects including severe skeletal abnormalities.

The EPA designated selenium and selenious acid in group D, not classifiable as a human carcinogen; selenium sulfide was designated in group B2, as a probable human carcinogen. Laboratory studies showed significant increases in the incidence of bronchial and liver cancer in laboratory animals that resulted from exposure to selenium sulfide.

### REGULATIONS ON HUMAN EXPOSURE

As a result of these adverse health effects and the threat to public health, federal regulatory agencies have established limits on selenium exposure. The EPA limits selenium in drinking water to 50 parts per billion (ppb) under the Safe Drinking Water Act. They further require the reporting of the release of 10 pounds (4.5 kg) or more of selenium sulfide. OSHA set a permissible exposure limit (PEL) for selenium of 0.2 mg per cubic meter of air over an eight-hour-day, 40-hour workweek. NIOSH set the same exposure limit (REL) of 0.2 mg per cubic meter of air over a 10-hour day. The immediately dangerous to life and health designation is for levels of 2 ppm for selenium hexafluoride and 1 mg per cubic meter for all other selenium compounds. The NIOSH 1972–74 National Occupational Hazard Survey estimated that 8,500 workers were exposed to selenium; the NIOSH 1982–83 National Occupational Exposure Survey estimated that 27,800 workers were exposed to selenium. In contrast to the restrictions to exposure, the Food and Drug Administration recommends a minimal intake of selenium of 70 micrograms per day for adults.

See also INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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### Seveso dioxin release Meda, Italy (July 10, 1976) Air Pollution

Meda is a small town about nine miles (15 km) north of Milan, near Italy's border with Switzerland. Tourists and townspeople regularly take leisurely walks along the wooded paths of the picturesque Seveso Oak Forest Park. Underneath the bike paths and pedestrian walkways are two large concrete tanks full of the poisonous residue of one of the most dangerous chemical spills since the beginning of the Industrial Revolution.

Since the early 1900s, a company named the Industrie Chimiche Meda Societa Azionaria (ICMESA) had been manufacturing chemicals inside a series of brick buildings just outside Meda. These products were shipped to chemical plants throughout Italy and Europe for use in the formulation of finished goods, including pesticides and flame retardants. Materials processed at the plant included 2,4,5-trichlorophenol, used in the production of pesticides, and a nuisance chemical by-product of pesticide manufacture, 2,3,7,8-tetrachloro-dibenzo-p-dioxin, more commonly known as TCDD, or dioxin.

### THE POLLUTION RELEASE

Saturday, July 10, 1976, started routinely at ICMESA, but inside an enclosed tank in Building B problems were beginning. At around 12:30 p.m., a mix of chemicals that had been left in the tank in midproduction cycle untended through the weekend started to react exothermically. Eventually, pressure built up inside the tank and caused a rupture disk within a safety valve to fail, and a plume of toxic gas, consisting primarily of steam and containing 2,4,5-trichlorophenol and dioxin, was released. It formed a towering cloud extending up to 150 feet (46 m) into the atmosphere. No workers were present inside the building, and the release was unnoticed for most of the day. The cause of the runaway reaction that led to the release and the reason that the chemicals were left unattended inside the tank in the middle of a production cycle have never been explained.

Slowly dispersed by a gentle southwest wind, the vaporized chemicals settled over the farms and homes of the nearby town of Seveso, 1.8 miles (3 km)



away. Although the amount of chemicals released into the atmosphere from the ICMESA plant has been difficult to confirm, most researchers think that about 1,400 pounds (636 kg) escaped, which included a quantity of dioxin ranging from 0.05 to 20 pounds (23 g–9.1 kg) or more.

Unsubstantiated reports surfaced that ICMESA was involved in chemical weapons research for the Italian government or the North Atlantic Treaty Organization (NATO) and this was why such large amounts of dioxin were present at the plant. Later investigations found no evidence to support these rumors.

### THE RESPONSE AND AFTERMATH

By today's standards, the response of the company and the Italian government over the next few days after this release seems criminally negligent. It was not until the following day that ICMESA managers informed the local authorities that a "cloud of

herbicide that causes harm to agriculture" had been released and suggested that local residents be notified not to eat vegetables from their gardens. By July 14, it started to become clear that the nonchalance of the company's announcement was out of proportion to the potential health effects of the release. Small animals began to die, and children started developing rashes.

Five days after the release, the local authorities finally began to suspect that something was seriously wrong. The deputy health officer declared a 30-acre (12-ha) zone downwind of the plant contaminated and ordered some 200 residents to evacuate. Under pressure from their parent company, the multinational pharmaceutical corporation Hoffman LaRoche, ICMESA officials grudgingly agreed to have a doctor examine workers who might have been exposed to the toxic gas. Later that day, ICMESA managers held a meeting with the mayor, and they produced a few maps showing where the gas cloud might have settled but otherwise did not



Warning signs being posted around Seveso, Italy, after release of a pesticide cloud containing dioxin, 1976 (© Hulton-Deutsch Collection/CORBIS)

offer much in the way of real information. ICMESA knew at this meeting that the material released contained dioxin, but they would not inform local officials of this for another nine days.

As the dioxin and other chemicals began to be incorporated into the local environment, residents began to notice that rabbits, often held as pets, commercially bred, or even seen in fields, were dying in alarming numbers. More importantly, the number of children who had burnlike skin lesions began to increase. Eventually, 13 would require hospitalization and emergency treatment. Within two weeks of the release, approximately 3,300 animals died. With fears over the extent of contamination spreading, the government ordered the slaughter of 78,000 farm animals, pets, and livestock.

By the end of July, the situation had overwhelmed local authorities, and the national government had mobilized the army. An additional 800 people were forcibly evacuated, and the contaminated and quarantined zone eventually extended to more than 3,700 acres (1,500 ha). More than 220,000 people from the five municipalities of Lentate sul Seveso, Seregno, Varedo, Muggiò, and Nova Milanese were affected, and almost 40,000 were seriously exposed. As is often the case in forced evacuations, especially those connected to environmental disasters where the risks often are not obvious and are difficult to explain, many relocated families returned to their homes in October and December 1976 before being once again made to leave by local authorities.

In late July, the Italian press finally recognized the severity of the situation, and banner headlines began to appear in major newspapers. ICMESA plant buildings were ordered closed, and company chemists confirmed that dioxin had been detected in soil and vegetation samples downwind of the plant. They also offered a map indicating where dioxin was found in the samples they had collected. Workers at the factory started to accuse governmental authorities of withholding information. Pregnant women from the affected areas were advised that existing laws against abortion had been waived and pregnancies that would be psychologically traumatic for the mother could be legally terminated. ICMESA's technical and production directors were arrested.

The most obvious near-term health affects of the release, 193 cases of skin rashes, were eventually reported and diagnosed as chloracne, a severe dermal disorder usually associated with exposure to high doses of chlorine and halogenated aromatic hydrocarbons. Its symptoms include an acnelike eruption of cysts, blackheads, and pustules on the cheeks, behind the ears, in the armpits, and around

the groin. The more severe cases did not clear up for years and left permanent scars.

By early August, the Italian government had committed more than \$80 million to the relief effort. Later in the month, Hoffman LaRoche agreed to pay for relocation, medical, and cleanup expenses. The regional government established the Giovanardi Commission to oversee, coordinate, and direct governmental response activities, including medical and epidemiological studies.

### THE CLEANUP

In September, with the public health crisis basically under control, the government and ICMESA turned their full attention to the cleanup. Jobs were found for the displaced ICMESA workers, and the remaining raw materials and chemicals were removed from the factory for disposal. By January 1977, cleanup efforts were under way in earnest, with the goal of making the area safe for reoccupancy and restoring it to productive agricultural use. Schools were decontaminated and water quality studies undertaken. Leaf litter, grass, and unharvested agricultural produce were collected and stored for later disposal. Epidemiological and medical monitoring programs were established to study the effects of the dioxin release on unborn children and cancer rates and death rates in the general population, as well as to monitor the health of workers at the ICMESA plant.

Even with all of their relief efforts, many of the residents and workers still thought they had been mistreated and ignored by both the government and ICMESA. In September, the director of the Seveso Health Department was shot in both legs. In 1980, ICMESA's production director at the time of the accident was shot and killed.

### LONG-TERM EFFECTS

The public health effects of the Seveso dioxin release were first documented in studies that began in 1977 and are continuing to this day. Chloracne was one effect that was clearly related to the disaster. Longer-term studies of liver function, immune function, neurologic impairment, and reproductive effects have been less conclusive. Excess mortality rate from cardiovascular and respiratory diseases was found among the survivors, possibly related to a combination of both chemical exposure and stress associated with the personal upheaval the accident caused to many individuals and families. The number of diabetes cases also increased. Cancer and cancer mortality rose, especially those associated with the

gastrointestinal system and lymphatic and hematopoietic tissue. These results, however, could not be definitively connected to the accident. The study is continuing in an attempt to overcome logistical limitations, such as limited individual exposure data, short latency period, and small population size for certain cancer types, and to explore new research paths.

One potential impact of the release that received widespread media coverage is that for the first seven years after the accident, more of the babies born to parents who had been exposed were females, 46 females compared to only 28 males. Typically, the numbers of female and male births are about the same. This change in the sex ratio was also reported for workers exposed to dioxin from an incinerator in Japan.

In October 1977, 500 evacuees were allowed to return to their new homes, after the old ones had been demolished. By 1985, most reclamation had been completed, and the ICMESA property had been converted to a park, the Seveso Oak Forest. In 1995, almost 20 years after the release, the cleanup was officially declared complete, all the residents had returned, and the final contaminated area was released for cultivation.

Deeply buried below the Seveso Oak Forest are two large concrete tanks into which has been placed 40 cm (16 inches) of TCDD-polluted topsoil, scraped off farms, roads, and backyards. Also resting quietly inside the tanks are the carcasses of the contaminated animals, the ICMESA factory, as well as the remains of the other buildings covered by chemical fallout after the release. Groundwater from these two basins seeps into another tank, where it is treated and released. This system is constantly monitored and will be for at least the next century.

See also AIR POLLUTION; DIOXIN; ORGANIC POLLUTANTS; PESTICIDES.

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**sewage treatment plants** One of the main problems that face society is disposal of wastewater. In many areas, it is handled on an individual level using a septic system. Sewage that is removed from homes and businesses through a public sewer system by law must be treated before it can be released. Before such laws were passed, water was withdrawn from rivers on the upstream side of cities and towns, and raw sewage was dumped into rivers just downstream of them. This practice resulted in highly polluted rivers and rampant disease including plagues, causing many deaths. It was because of these problems that regulations were established to purify the water and improve public health. In a plant, wastewater is treated by using primary treatment, secondary treatment, and advanced treatment.

## SEPTIC SYSTEMS

In America, septic systems are the most common form of waste disposal in areas without sewers. It is estimated that roughly one-third of sewage is disposed of by septic systems. In these systems, sewage is removed from the home through a system of drainage pipes, which coalesce into a single master drain. The sewage first flows into a settling tank, where solids settle to the bottom and are thereby separated from the liquids. The liquids either are discharged into leach beds or drain into dry wells. The sewage enters the leach beds through perforated drain tiles and percolates into the soil below. The dry wells are vertical perforated culverts beneath the settling tank, where fluids may percolate. The idea is that the liquid waste will be purified by percolation through soil before entering the water table. In many areas under certain conditions of soil and home density, the systems perform acceptably. In many other areas, they produce contaminant plumes in shallow unconfined aquifers that can affect adjacent wells or surface water bodies. With time, the settling tanks fill with solids and must be pumped out and into a truck from a septic service.

These systems can handle only a small amount of wastewater at any given time and can easily fail if overwhelmed. Output from these systems is rarely





Settling tanks are used to allow treated water to clarify through solids sinking to the bottom of the vessel, where they can be removed for further treatment and disposal. (Chris Knapton/Photo Researchers, Inc.)

monitored, and it can have a negative impact on water quality in an area, leading to many lawsuits. It is for this reason that public sewers that transmit the sewage to wastewater treatment plants are used on an ever-increasing basis.

### WASTEWATER PREPRIMARY TREATMENT

Typically, there is a preprimary treatment performed on the wastewater to screen out, grind up, or sepa-

rate debris. Debris may include sticks, rags, large food particles, sand, gravel, and toys, depending upon the source. This debris is removed to protect the pumping and other equipment in the treatment plant. Treatment equipment includes bar screens and grit chambers, and comminutors, which are large versions of garbage disposals, are used as the wastewater first enters a treatment plant to remove debris. In some instances, the wastewater may be first sent to a settling lagoon before processing.



### PRIMARY TREATMENT OF WASTEWATER

Primary treatment involves screening and sedimentation. Screening is done by passing the wastewater through a filter or screen, which removes grit including sand and stones and other large particles. The rest of the particulate is allowed to settle out of the wastewater in a tank to form an organic-rich mudlike sediment, called sludge, which is then piped to the digester. The remaining wastewater has had about 30–40 percent of the pollutants removed and is pumped into the secondary treatment section.

### SECONDARY TREATMENT OF WASTEWATER

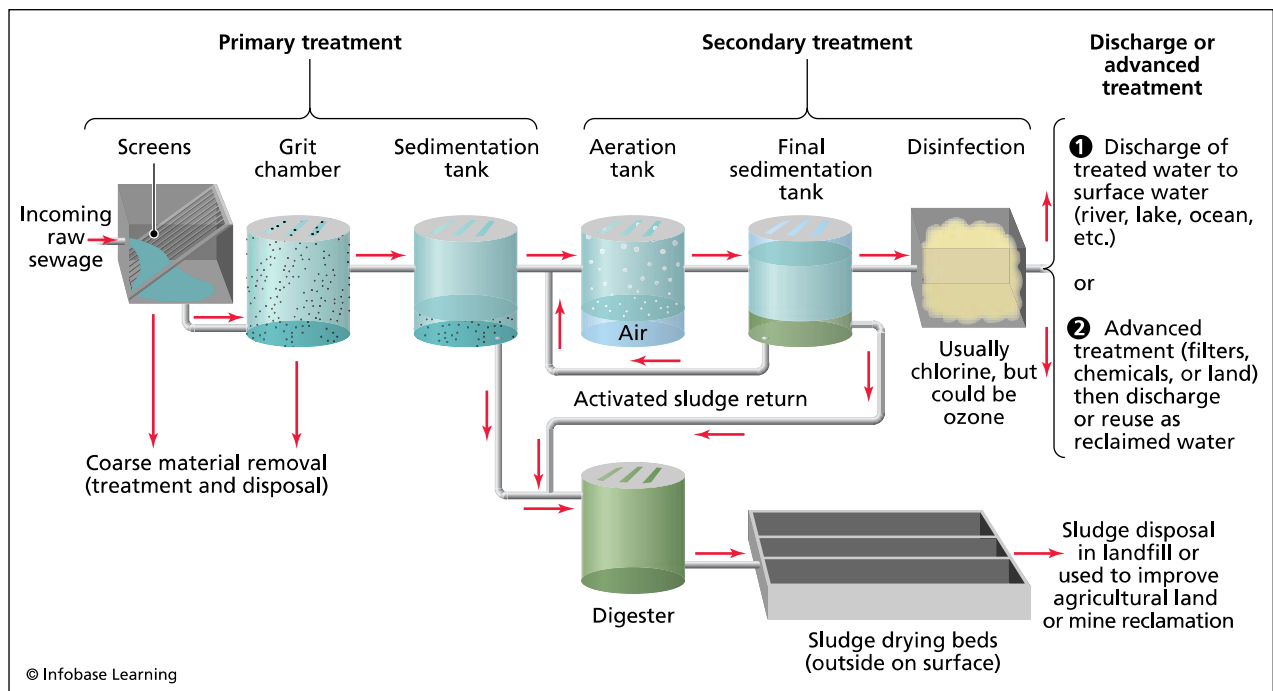
Secondary treatment begins with the pumping of wastewater into an aeration tank, where air is pumped in and aerobic bacteria break down most of the remaining organic material. Wastewater is pumped to the final sedimentation tank, where the remaining sludge settles out. Most of that sludge is also pumped to the digester. The remaining sludge is sent back to the aeration tank to act as a bacterial starter for the new sludge. The sludge in the digester undergoes further decomposition through the actions of anaerobic bacteria. The processes in the digester further reduce the organic component but also have as a by-product methane gas, which can be collected and used as fuel. About 90 percent

of the organic component of the waste, termed biochemical oxygen demand (BOD), is removed by the time it has passed through secondary treatment. The waste, however, still contains some nutrients such as nitrogen, phosphorus, and heavy metal, as well as manufactured compounds such as solvents and pesticides. The final stage of secondary treatment is disinfection of the wastewater, typically using chlorine but also using ozone or even ultraviolet radiation, in some cases. Usually, at this point most of the wastewater is returned to surface waters, though, in some areas, it is pumped into injection wells. The remainder can be sent on for advanced treatment.

### ADVANCED TREATMENT OF WASTEWATER

Advanced treatment is undertaken to remove nutrients, heavy metals, and other chemicals of interest. This step is only taken if high-quality treated wastewater is needed for uses such as wildlife habitats or irrigation for crops, parks, and golf courses. This treatment usually involves sand and carbon filters and raises the removal of pollutants from the wastewater to 95 percent. Wastewater that has had advanced treatment is referred to as reclaimed water.

*See also* EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; INORGANIC POLLUTANTS; ORGANIC POLLUTANTS; PESTICIDES.



**Diagram showing the path and components of a modern sewage treatment plant with primary, secondary, and possible advanced treatment**

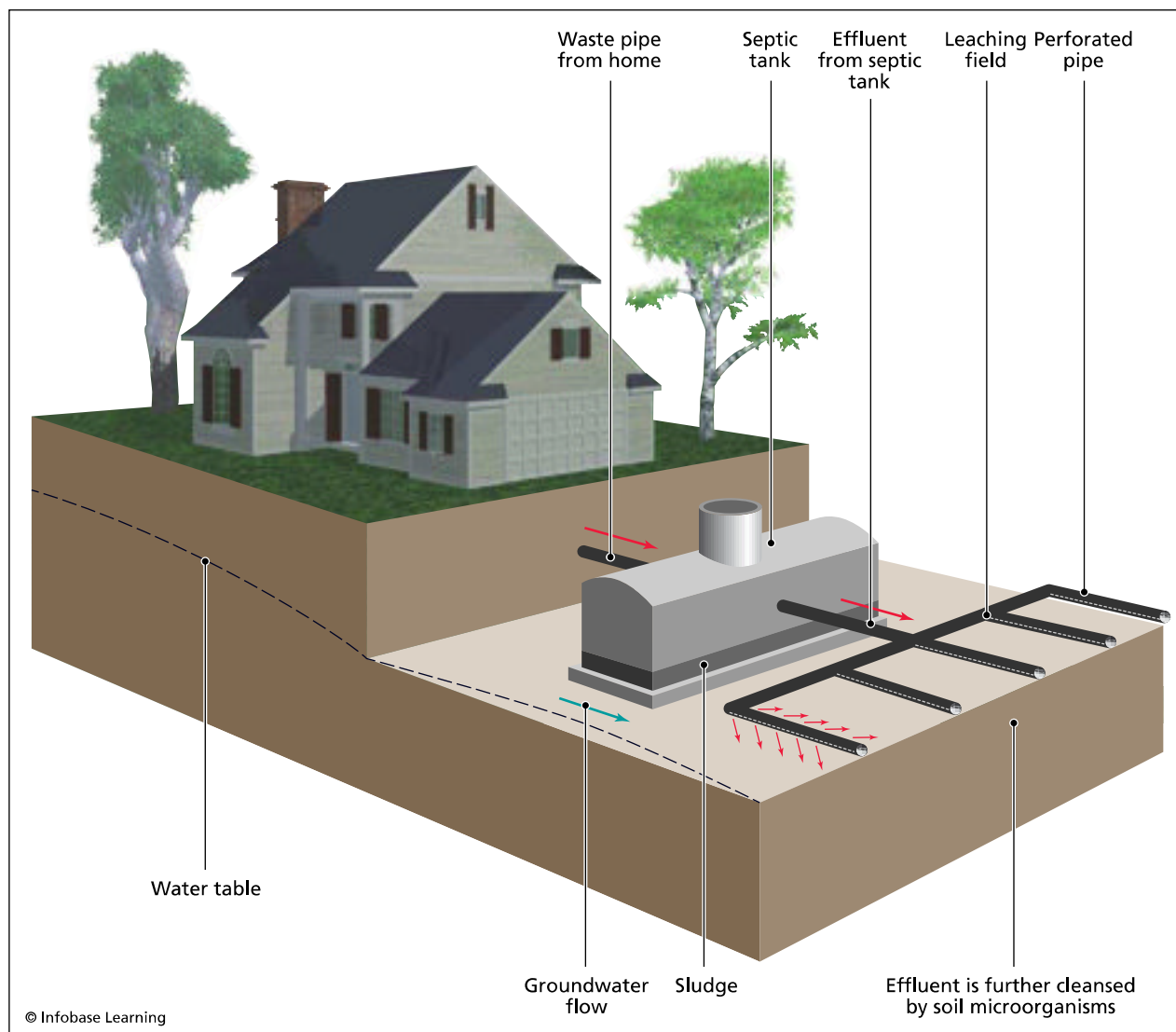


Diagram showing the basic components of a single-dwelling septic system including a tank and septic field

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**Sierra Club** The Sierra Club is America's oldest and best established citizen environmental organization. It is also the most credible and well respected of the environmental organizations and, as such, is most commonly solicited for opinions and information for environmental issues. The Sierra Club has evolved over the years from an organization that was mainly concerned with land preservation and outdoor excursions for its members to one that also includes a significant component of environmental activism. The current mission statement of the Sierra Club is as follows:

1. Explore, enjoy and protect the wild places of the Earth.
2. Practice and promote the responsible use of the Earth's ecosystems and resources.
3. Educate and enlist humanity to protect and restore the quality of the natural and human environment.
4. Use all lawful means to carry out these objectives.

Many of the goals of the Sierra Club and issues it addresses are the same as those of Greenpeace International, but they are, in general, not nearly as radical or outwardly confrontational. The Sierra Club engages in protests, legislative action, and legal action in an organized and effective manner to carry out the serious goals of its mission. It is, however, a recreational organization, and that remains the common thread that unites the group.

### HISTORY OF THE CLUB

The Sierra Club was founded by John Muir and 182 charter members on May 28, 1892, in San Francisco, California. The main effort for the club was to prevent the reduction in size of Yosemite National Park. John Muir would serve as president from 1892 until 1914. By 1899, the club had more than 350 members and was able to influence the establishment of Mount Rainier National Park. In 1901, the Sierra Club had its first outing, a tradition that would become the trademark of the organization. Naturally, the club chose to visit Yosemite National Park. By 1907, the club was dealing directly with the U.S. secretary of the interior, in this case, to oppose the damming of the Hetch Hetchy Valley in California. The following year, membership reached 1,000 people. In 1911, the Sierra Club had gained enough influence that the Devil's Postpile National Monument was established primarily through their efforts. The same year, the first local chapter of the Sierra Club, the Angeles chapter, was established in Southern California. In 1916, the club helped to establish the U.S. National Park Service, and the Sierra Club member Stephen Mather was appointed the director. In 1927, after lengthy efforts by the club, California established a state park commission and named the Sierra Club secretary, William Colby, the first chairman. By 1930, the club membership had surpassed 2,500. In 1934, another famous American, Ansel Adams, joined the board of directors and became almost synonymous with the club. He remained on the board until 1971. With time, the influence of the club grew stronger, as did its reputation. It developed enough influence actually to oppose efforts by the U.S. government and prevail. In 1943, the Sierra Club successfully defended the Jack-

son Hole National Monument against government officials who opposed it. In 1949, many years of effort came to fruition when both the secretary of the interior and the secretary of the army rejected the Glacier View Dam project in Glacier National Park, which they had opposed. In 1950, the Atlantic chapter of the Sierra Club was established. It was the first chapter outside the state of California and comprised 18 states and the District of Columbia.

David Brower, another pillar of the Sierra Club, became its first executive director in 1952, a position he occupied until 1969. During this time, many projects were undertaken, many of which changed the shape of American national parks. A complicated battle at that time was the saving of Dinosaur National Monument almost completely through club efforts. In 1956, membership reached 10,000, and by 1960 it was 16,000. A major change in emphasis for the club occurred in 1963, when an office was opened in Washington, D.C., specifically to address elected officials. Perhaps, in part, as a result, the U.S. Congress passed the Wilderness Act in 1964 as the first wilderness protection legislation in the world. This was considered a great victory for the Sierra Club because it had lobbied so hard for its passage. The Sierra Club underwent great expansion through the 1960s, including the establishment of a Sierra Club of Canada in 1963. By 1970, there were 114,000 members and club chapters in all 50 states. With the increased popularity and resources, the club began filing lawsuits to help protect the environment. In 1969, it won a suit to stop pollution in Lake Superior, thus shifting the direction toward antipollution, as well as land preservation.

The increased activism in pollution reduction corresponded with the lobbying, passage, and enactment of the National Environmental Policy Act, which established the U.S. Environmental Protection Agency. The shifting priorities of the nation allowed the Sierra Club to shift its policies and efforts toward pollution reduction. In 1972, the Sierra Club filed a lawsuit that led to a ban on domestic use of dichlorodiphenyltrichloroethane (DDT). It led an effort that defeated legislation to overhaul public land laws to favor commodity interests. It led efforts that would ultimately result in the passage of the Water Pollution Control Act over a veto of the then-president Nixon. In 1975, a Sierra Club lawsuit expanded the National Environmental Policy Act to cover actions of the United States involving marine and international situations. In 1977, the club persuaded the then-president Jimmy Carter to route the national gas pipeline around the Arctic National Wildlife Refuge in Alaska. In addition to these examples of sweeping

legislative changes, there were numerous actions on the regional scale to increase holdings of national and local wildland parks and preserves, prevent the damming and alteration of rivers and wetlands, and reduce harvesting of commodities from national lands.

By 1981, membership in the Sierra Club had reached 200,000, and by the next year, it was 325,000. Part of the reason for the increased interest was the very public conflict between the then-secretary of the interior James Watt and environmentalists from all sectors, led by the Sierra Club. Much of the beginning of the 1980s was spent attempting to preserve the victories of previous decades. Efforts to reduce the standards of the Clean Air Act, selling of public lands to industry, and allowing of energy exploration in wilderness areas were largely repelled but at no small cost to the resources of the club. In 1982, they attempted to influence legislation by actively participating in the 170 midterm congressional contests as well as in 150 state and local contests. In the end, 80 percent of the Sierra Club-backed candidates won the elections, and this may have been a contributing factor in the resignation of James Watt the following year.

After this regrouping, the Sierra Club became even more involved in influencing legislative decision making, although the tide of support gained through earlier work was self-sustaining in many cases. A Sierra Club lawsuit forced the EPA to regulate the release of radioactive pollutants in 1984. In 1985, the club worked diligently to help ensure the reauthorization of a strengthened Superfund and Clean Water Act. In 1990, a strong effort by the Sierra Club helped to enact a strengthened Clean Air Act in spite of a threatened veto by then-president George H. W. Bush. In 1993, the Colorado wilderness bill was enacted thanks to a decade-long club campaign, as was the California Desert Protection Act in 1994 after an eight-year fight. In 1996, the Sierra Club won a Clean Air lawsuit in Colorado that resulted in a record settlement for a suit filed by private citizens. It required \$145 million to install emission controls in power plants and \$4 million in penalties to clean air pollution in the Mount Zirkel Wilderness.

### CURRENT PRIORITIES AND ACTIVITIES

The Sierra Club currently has more than 1.3 million members and is as active as ever. They list several areas as their current priorities and initiatives for at least the next few years. These priority campaigns include:

1. Stop sprawl and revitalize communities.
2. Protect and restore wildlands.

3. Protect and restore national forests by ending commercial logging on federal public lands.
4. Defend the Clean Water Act, protect streams and wetlands and reduce pollution from corporate animal factories.
5. Curb global warming and promote safe, clean energy.
6. Fight for “clean, green and responsible” trade policy.
7. Promote family planning and work to stabilize world population.
8. Protect the human rights of environmental activists worldwide.

Many of these priorities have been the same for decades and some for most of the history of the club. Priorities 4, 5, and 6 deal directly with pollution but are similar to the actions of other environmental groups. By virtue of its size and reputation, the Sierra Club may be able to encourage improvement in these areas better than most other organizations, but these are all tall tasks with no easy solution.

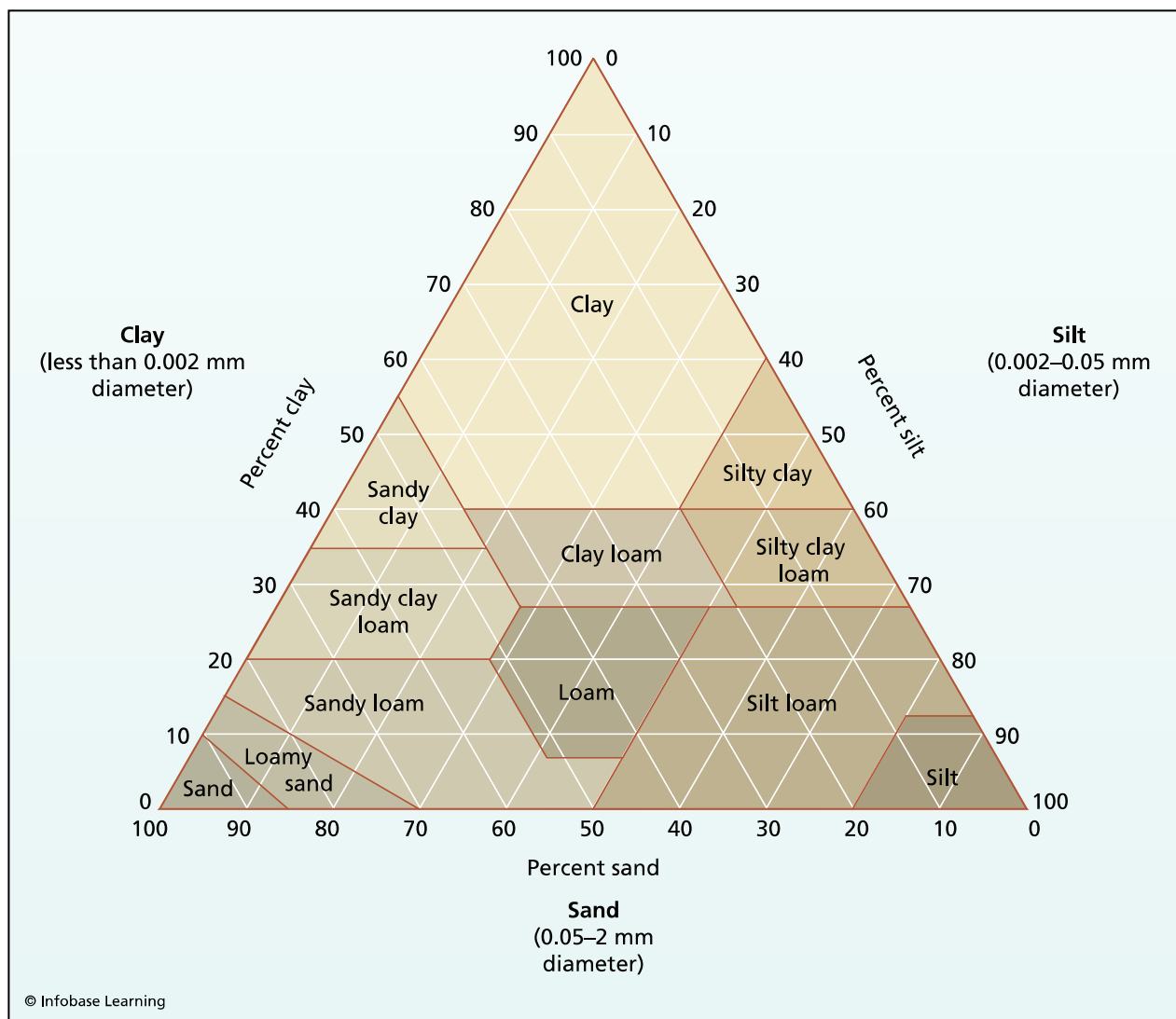
Some controversy surrounds priority 7. The Sierra Club is of the opinion that the runaway overpopulation of the Earth by humans is significantly degrading the environment. The population should be stabilized and ultimately reduced if we ever hope to achieve sustainability. In the mid-1990s, some of the members of the Sierra Club were in favor of controlling the population of the United States as a first step toward this goal. In order to stabilize the U.S. population, immigration would need to be controlled, since much of the growth results from that sector. A splinter group was formed called the Sierrans for U.S. Population Stabilization but was opposed by the vast majority of the membership, who wished to remain neutral on the issue of immigration. The idea surfaced several times and was even a ballot issue, but it never amounted to much and appears to have been dropped.

See also DDT; ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; GLOBAL WARMING; GREENPEACE.

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**Ternary graph of the classification system for soil based upon grain size.** By determining the proportion of sand, silt, and clay in a soil, a point may be plotted on the graph, and the field that it falls into determines the soil classification.

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**soil** Soil is one of our most precious resources, and yet it is regarded with disdain by most humans. Many common sayings in many languages bear this out. The vast majority of our food supply either is grown directly in soil or survives only because it

feeds on the food grown in the soil. Were it not for soil, very little life would be possible outside the oceans.

By definition, soil is all unconsolidated material lying above bedrock and formed by the surficial processes of the Earth. It is composed of rock in various degrees of mechanical and chemical breakdown, organic detritus in various forms, microorganisms of various forms, and various forms of materials added by natural and artificial processes. With such a cumbersome definition, it is no wonder that the classification of soils takes on various forms. There are a textural/chemical classification, a classification by structural development, and a classification by regional associations.

## SOIL MATERIAL CLASSIFICATION

There is a simple classification of soil composition based upon the components of clay, silt, and sand. This system is displayed on a ternary graphical diagram in which there are subdivisions into compositional fields with some basic names. Either the soil is composed of one of the three end members (clay, silt, and sand), or it is composed of some mix of two or three, called loam. Most soil is some form of loam. Depending upon the composition of the clay, the soil name can be further modified. There are numerous types of clays; chemical analysis is required to identify them in most cases. These clays can adsorb certain elements, so they can be important sources of nutrients or dangerously polluted.

## SOIL HORIZONS

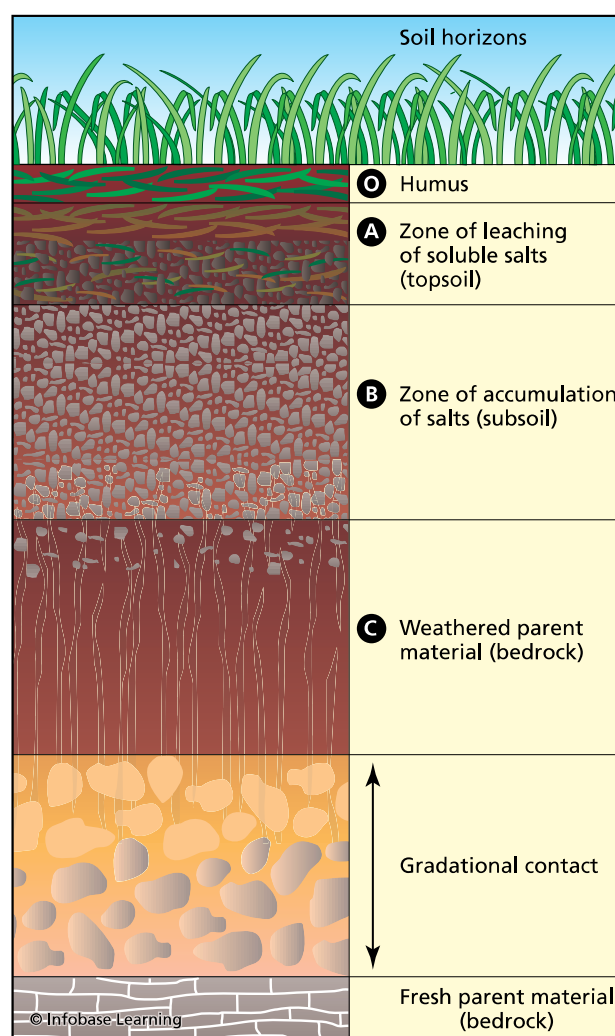
Soils also form characteristic profiles if they are residual or formed from the weathering of the underlying bedrock. In this case, they develop horizons. At the surface, the O horizon is completely organic and composed of decaying leaf litter. It is sometimes called humus and is almost always home to plants and animals. The A horizon is the next down and commonly called topsoil. It, too, is organic-rich but also contains clays and other evidence of decayed rock. It is home to much biologic activity. The underlying B horizon is commonly referred to as subsoil. Unlike the overlying horizons, which are dark, the B horizon is generally tan and clay-rich. It commonly contains fragments of partially decayed rock and only roots of trees and other large plants. There are certain animals that burrow into the subsoil but far fewer than in the upper horizons. The C horizon is composed primarily of fragments of bedrock in various stages of decomposition.

The development of each of the horizons depends upon the local environment. In arid areas, there is little vegetation, and consequently the O horizon is typically absent or poorly developed at best. Glaciers removed most of the soil during the last ice age. A result is that the O horizon may sit directly on bedrock or on glacial sediments in many areas, such as the northern United States, with minimal A, B, or C horizons. In old, deeply weathered terranes such as the southeastern United States, the A, B, and C horizons may be quite thick, 50 feet (15 m) or more. The soil retains the layering and structure of the parent rock, but all of the minerals are altered to clay, iron oxides, and relict quartz. This material is called saprolite.

## SOIL STRUCTURE

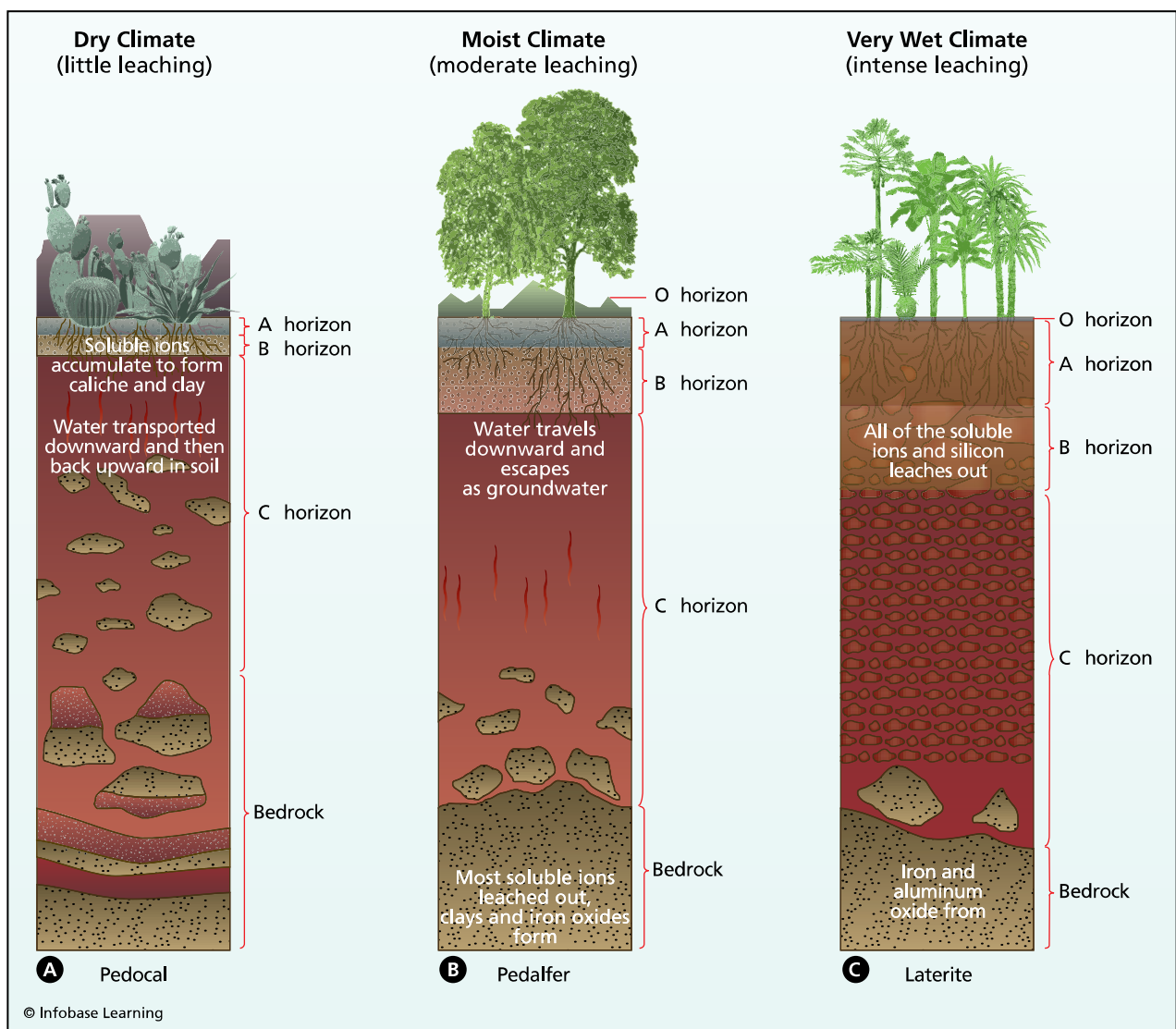
There are five recognized categories of soil structure based upon the shape with which they break apart under natural conditions. Some soils have no structure and are massive, as are many soils that are worked by humans. The five types are described as follows:

1. *Platy* soil structure means that soil breaks relatively easily into flat, generally horizontal, plate-like aggregates. The plates are lenticular-shaped in some areas and generally impede infiltration of water and downward growth of roots. Platy structure is found in B and C horizons that have



**Illustration of a standard soil profile showing the soil horizons. In the top horizon, O is organic, but the other horizons are just labeled for their order, top to bottom. Not all horizons are present in all soil profiles and their thicknesses can be highly variable.**

- been extensively leached or flattened by animals or machinery.
2. *Prismatic* soil structure is characterized by aggregates that are separated by flat to rounded vertical faces and rather indistinct prism-shaped tops. These structures are common in B horizons, where there are extensive wetting and drying, freezing and thawing, or strong downward movement of water or growth of roots.
  3. *Columnar* soil structure is similar to prismatic structure, but the vertical cracks are deeper and the prism-shaped tops are more distinct. The structure is relatively pervasive and gives the soil a columned or palisades look.
  4. *Blocky* soil structure occurs when the aggregates are relatively equidimensional with flat to slightly curved cracks or edges. They may be angular if the edges are straight or subangular if they are somewhat curved. They are common in areas of high swelling clay content.
  5. *Granular* soil structure occurs where the aggregates are rounded and do not fit together as most of the other categories do. Mechanical working tends to reduce the size of the aggregate.



**Representative soil horizons for three common types:** Pedocals are rich in calcite (cal) and common in dry areas such as the southwestern United States (A); pedalfers are rich in aluminum (Al) and iron (Fe) and are common in temperate areas with plentiful rainfall like the eastern United States (B); and laterites are very rich in aluminum and are common in tropical climates with plentiful rainfall (C).



**Map of North America showing the distribution of general soil types (see text for description of the soil types). A soil map of specific areas would be needed to determine local soils.**

gates. They drain well and can accumulate organic material, making them relatively fertile. They are common in rich grasslands and many tilled areas.

### SOIL TYPES

Soil in the United States is also traditionally classified into types primarily by general compositional characteristics developed by long-term weathering.

In this traditional classification system, the most common are pedalfers, pedocals, and laterites:

*Pedalfers.* Soils that are rich in aluminum and iron. They are common in temperate areas where there are significant rainfall and vegetation. Acid from decaying vegetation dissolves out most minerals, especially those rich in calcium and alkalines. These soils are common in the northeastern United States.

*Pedocals.* Soils that are rich in calcium. They occur in very dry climates that are typically hot.



They develop hard pans that are like cement in some cases and commonly contain caliche. Pedocals are common in the southwestern United States.

*Laterites.* Soils that are extremely rich in aluminum. They are common in very rainy tropical areas, where weathering is very deep. Acids from decaying vegetation remove everything but aluminum and some clay. They can develop into bauxite, which is mined for aluminum.

The modern system of soil classification in the United States is more complex and comprehensive to take into account the great variations in texture and composition. This U.S. Comprehensive Soil Classification System includes 12 major orders of soil based upon both environment and physical character, although many are very minor. There are huge numbers of suborders of each order and some 19,000 soil series beneath them. There are also numerous other world classifications that are not included in the American system and are described as follows:

*Alfisol.* A young soil that is gray-brown in color and forms in humid forests but under a variety of conditions. It is rich in clay and plant nutrients. *Alf* refers to aluminum (Al) and iron (Fe), making it essentially equivalent to a pedalfer, indicating that they are found all over the eastern United States, among other places.

*Andisol.* A soil type that forms in volcanic ash. These soils are composed of altered glass and unstable mineral fragments and, as such, undergo rapid changes in composition. They are very fertile, supporting a huge variety of crops, but they are regionally restricted. The Cascades, Aleutians, and Hawaiian Islands contain the best examples of this soil in the United States.

*Aridisol.* A soil that forms in the desert and is equivalent to a pedocal. It has low organic components and accumulates minerals that are normally removed by water.

*Entisol.* A very young soil that is lacking in structure and shows characteristics of the parent material. These soils form in areas that are very active or slowly weathered. They may form on active slopes or in rivers and are common in the Rocky Mountains and Basin and Range Provinces and in California. They tend to be very fertile, but because of physical instability or extreme conditions, they may, in many cases, not support significant vegetation.

*Gelisol.* A soil type that is young and forms in areas of permafrost. These soils are frozen a good part of the year, so soil profile development is slow and poor. They are typically just A horizon resting on permafrost. Although the organic layer may be quite fertile, the extreme weather conditions greatly limit the development of vegetation of any kind.

*Histosol.* A black, highly organic-rich soil commonly referred to as peat and muck. It is composed almost entirely of partially decomposed vegetation and is therefore only O horizon. There are no climate implications for histosols, although presently they are more common in swamps along the southern and eastern coasts and in bogs along the northern border (areas affected by glaciation) of the United States.

*Inceptisol.* A young soil in which a recognizable profile is at its initial stages of development. It tends to form relatively quickly through alteration of rock and sediment in humid climates. It is most common in the forested northwestern and glacially scraped northeastern parts of the United States.

*Mollisol.* A soft, dark-colored soil that most commonly develops from long-term growth of grass. It is a highly fertile, organic-rich soil with good A horizon development and high calcium and magnesium contents. Mollisols are also among the newer types of soils because extensive grassy areas only developed in the Eocene. They are characteristic of prairies and, as such, underlie the entire Great Plains of the United States. They can occasionally form in forested areas, where there is extensive earthworm activity, but this is rare.

*Oxisol.* A highly leached soil that forms in tropical climates and is equivalent to a laterite of the old system. This soil type tends to be infertile because of the extensive leaching and is very rich in aluminum with lesser amounts of iron, all in oxide form, thus the name. The vast vegetation that grows on this soil type in rain forests actually grows in the leaf litter above it. Although the soils of the deep southeastern United States approach oxisols, the only true modern oxisols may occur in some of the tropical islands of the U.S. possessions. They are much more common in Central and South America.

*Spondosol.* A soil that occurs only in humid regions on a sandy substrate. The A horizon is composed of weathered organic material, but the B horizon contains light-colored leached material, which is the distinctive feature of this soil type. These soil types are common in cool, humid pine forests of the northern United States and some minor areas at higher elevation.

*Ultisol.* A highly leached red to yellow soil that forms through long periods of weathering. It is characterized by low fertility and is highly acidic, rich in aluminum and iron, and poor in calcium. The *ulti* part of the word is from *ultimate* because it is the ultimate product of weathering. These soils are common in the southern and southeastern United States.

*Vertisol.* A soil that is characterized by a high content of expanding clays. This soil is common in

arid areas with wet and dry seasons, forming deep vertical cracks when dry and puddles when wet. It commonly forms through the weathering of basalt and can be found in Colorado and other areas of the western United States.

### POLLUTION OF SOIL

Soil is polluted on a daily basis at numerous levels of volume and impact. As a result of this pollution, there is an ongoing battle between polluters adding pollution and remediators removing it that determines the total amount of polluted soil. Although there has been pollution of the soil dating from the first settlement of humans, the industrial age turned this largely inconsequential and recoverable pollution into a major epidemic. The complete lack of regulations on industry for hundreds of years left a legacy of soil pollution in virtually all the old industrial centers. Many of the specific company sites in these areas are current Superfund sites. Now, as a result of efforts by the U.S. Environmental Protection Agency (EPA) and many state and federal agencies, the spread of soil pollution is somewhat controlled. Cleaning up the legacy of pollution, however, will take many decades and cost billions of dollars.

Pollution can enter the soil in a variety of ways. Most simply, it can be dumped directly on the soil surface in a dump or landfill. Entire communities have dumped their refuse in large pits to dispose of it. Not only has the refuse polluted the soil directly, but polluted fluids, called leachate, have then been emitted from the landfill or have been produced by passing rainwater and other precipitation. This leachate has further polluted deeper levels of the soil beneath and around the landfill by infiltrating it and depositing pollutants. This practice largely ended in 1976, when the U.S. Congress passed the Resource Conservation and Recovery Act (RCRA), which required that all dumps be converted to sanitary landfills. After this, landfills had to be engineered and constructed to prevent leakage and restrict pollution.

Landfills and dumps produce point source pollution, because the source can be uniquely identified. Other point source pollutants include spills and leaks from manufacturing, transportation, and storage facilities, as well as disposal wells, septic systems, industrial lagoons, underground storage tanks, and many sources in residential dwellings. There are also many nonpoint source pollutants that do not have identifiable sources. These include pesticides that are sprayed onto the soil surface or mixed into the soil, air pollution deposition onto the soil by gravity fall-

out or precipitation washout, fertilizers, road salt, and other road grime, among other sources. All of these processes spread pollution into soil.

Once the pollution is in the soil, it may be fixed and immobile or mobile and able to leach into the groundwater. The mobility of a pollutant depends on its chemistry. Generally, water-soluble pollutants are mobile because they can be dissolved in infiltrating water from precipitation and carried away. This process cleans the soil but affects the groundwater. Most heavy metals and other chemically stable solids do not dissolve or chemically react to form compounds that may be flushed out. They essentially form sediment in the soil and remain fixed. Many organic pollutants adhere to clay and organic particles in the soil by chemical processes and remain fixed. Some of these and the mobile organic compounds are broken down to less harmful compounds through the action of microorganisms, which use the pollutant as a source of food and clean up the pollutant in a natural form of bioremediation. This and other natural pollutant removing processes are known as natural attenuation. The most difficult problem arises with some of the pesticides, because they kill the microorganisms. In this case, they can be very persistent, remaining active in soil for decades. This is the case with dichlorodiphenyl trichloroethane (DDT), but there are several other pesticides in the same category.

*See also* BIOREMEDIATION; DDT; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; GLACIAL DEPOSITS; IN SITU GROUNDWATER REMEDIATION; LANDFILL; LEACHATE; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; STREAMS; SUPERFUND SITES.

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**soil pollution** The soil of the planet Earth has been a dumping ground for refuse since the beginning of time. Prior to the Industrial Revolution, this did not present much of a problem except for mining and smelting operations because most waste was biodegradable. Left alone, the impacted area would quickly return to its natural state. In the case of mining operations, the waste rocks that were removed from underground do not biodegrade, carry potentially dangerous compounds to the surface, and can take hundreds to thousands of years to break down. If they are smelted, the result is even worse. Smelting is the first step in chemical refining: It splits the chemicals in a mineral compound to yield a target element, usually a metal in ancient times, and waste elements. The waste elements could include sulfur and sulfur compounds that could cause local acid rain and acid mine drainage as well as unanticipated heavy metals such as mercury, lead, chromium, and cadmium. Any of these contaminants could cause severe environmental problems. Fortunately, mining and smelting operations were generally small for most of human history.

The Industrial Revolution changed this relatively sustainable human existence. The first major pol-

lutant was coal, which remains a problem today. In addition to all of the soot it produces and unwanted air pollutants it releases, the mining and storage of coal can produce significant pollution. If coal mining and usage had remained a small operation, the environment could have absorbed much of the pollution. It did not. Coal mining and usage supplied the power for the Industrial Revolution and spread everywhere by trains. Between the dust and the contained impurities such as sulfur, mercury, and other heavy metals, coal caused significant widespread soil pollution by emissions and dumping of waste. The practice of simply dumping waste and producing emissions no matter how dangerous and unsightly became the norm for the Industrial Revolution. As more dangerous compounds were developed, the practice did not change, and pollution intensified and increased. It was not until the advent of the environmental movement in the 1960s and 1970s that the practices would change and even then, only because they became illegal and had a steep cost attached to them. It would be even longer before a significant proportion of the population became concerned about damage to the environment.



Installation of a residential-type septic tank (AP Images)



There are several problems associated with contaminants in soil. If they are soluble contaminants, infiltrating water can leach them into the groundwater system and contaminate drinking water supplies. Some can be taken up by plants and incorporated into the leaves, stems, and fruit. If they are immobile, erosion can remove the soil and transport them as particles into surface water and contaminate it and the sediments deposited at the bottom. Some contaminants can evaporate from the surface of the soil, or the soil can dry out and be carried away by the wind as particulate, both processes contributing to air pollution. In these ways, soil pollution can contribute to pollution of all other media.

### HEAVY METALS IN SOIL

Heavy metal pollutants include the metallic elements that are considered to be potentially dangerous. Originally, the term applied to metals with density greater than 6.0 g/mL, but this reference is not strict any more. Heavy metals are emitted to the soil by mine waste, settle out (fall out) or are washed out (by precipitation) from air pollution, and from direct dumping. These heavy metals—including arsenic, cadmium, chromium, lead, mercury, and zinc, among others—can be emitted in various compounds with a number of valence states. These conditions determine how immediately toxic each will be. For example, dimethyl mercury is highly toxic in very small quantities, whereas in nonmethylated states, it is far less dangerous. Hexavalent chromium is more dangerous than trivalent. The concentration of the heavy metal is also important. Many of these metals occur naturally in rock and soil in very small quantities and are relatively unimportant pollutants. If concentrated by natural or anthropogenic processes, they become far more hazardous.

As far as high concentrated levels of pollutant, mine wastes are certainly among the worst. Minerals with high amounts of heavy metals are commonly relatively unstable at the Earth's surface. The deep weathering of rock surfaces that occurs over the thousands to millions of years that develop most landscapes generally breaks down such minerals. Through hydration and oxidation reactions, they are removed to clays and other minerals and dispersed. When mining takes place, fresh unweathered and highly reactive minerals are taken to the surface and exposed to the elements. In addition, the rocks are crushed into small pieces. The smaller the fragment, the more surface area it will have. Mine tailings, therefore, have highly unstable minerals with high surface area upon which chemi-

cal reactions may take place. These chemical reactions release the heavy metals that are concentrated in most metallic deposits from the minerals and into the environment. The initial weathered material from mine tailings is highly enriched in heavy metals and can cause environmental health issues in the area. With time, these emissions will lessen, but they will remain well above background levels for centuries. For these reasons, mine soils can be great sources of pollution.

Direct dumping of waste from industrial sources also contributes toxic doses of heavy metals to the environment. Commonly, the metals in industrial waste are in their most hazardous state. For many decades, industry simply dumped waste solids and wastewater on the ground outside the manufacturing facility. The concentrations of these metals are as high as or even higher than would be found in a natural deposit of them. Berry's Creek, New Jersey, for example, has a Superfund site where there are layers of liquid mercury in the soil strata. It is the most polluted mercury site in the world. There are examples of such dumps for every heavy metal.

Heavy metals may also contaminate soil by air pollution fallout or precipitation washout. This process can occur in a number of places. Manufacturing facilities can release metals into the air as dust or vapors, especially in metal processing facilities. Incinerators have historically released metals in the fly ash from smokestack emissions. Coal-burning plants may release mercury and other metals along with sulfur compounds that can be carried by the air and deposited on the soil. The concentrations of the contaminants are highest in soil closest to the source and gradually decrease away from it. Concentration is typically highest in the direction of the prevailing winds. With recent stringent regulations on smokestack emissions of many pollutants including mercury, for example, requiring scrubbers and other emission reduction devices, there are fewer contaminants being deposited today. The legacy of old pollution, however, can be quite intensive.

Unlike many other damaging soil contaminants, such as phosphorus and sulfur, heavy metals are typically tightly fixed in the soil and remain for a long period. Unlike organic pollutants, they cannot be converted into other, less dangerous chemicals other than by changing valence states. Almost all cannot be leached into the groundwater system to any appreciable amount, as sulfur, phosphorus, and many organic contaminants can. Some can undergo limited bioconversion from one valence state to another. Some plants such as tobacco can take up certain metals into the plant structure. Otherwise,



## GOLF COURSES AND POLLUTION

There are few sports that are as intimately tied to the land and its topography as golf. Although the game's origins are unclear, with France, China, and the Netherlands laying claim to having developed a form of play as early as the 13th century, it is Scotland that is most often mentioned as the place where the modern game of golf, or *kolf* (Dutch for "club") first became recognizable. Thought to have been devised by bored shepherds competing to hit rocks as far as they could with their staffs, the links were rabbit holes connected by paths in the grass trodden down and widened by predators, sheep, and people. Fairways, a Scottish nautical term for the easiest sailing route between two ports, took advantage of the local topography and geology. In the most famous golf course in Scotland and probably the world, St. Andrew's, water hazards are flooded glacial potholes, and sand traps are places where glacial outwash had deposited reworked fine silt and sand. Despite this intimate connection with the land, however, golf is not a particularly environmentally friendly game.

There are about 15,000 highly manicured golf courses in the United States today. Unless they are properly designed and managed, courses can require extensive amounts of energy, agricultural chemicals, and water to maintain their functionality. Although the clubhouse may be the social focal point of a golf course, the maintenance department is its true center. It is at the maintenance shed or building where equipment for irrigation and mowing and spare parts are kept and stored, along with fuel, cleaning solvents, fertilizers, and pesticides. The two maintenance activities that can have the most impact on the groundwater underlying a golf course are fertilizing and pest management.

Golf courses are covered with turfgrass, a type of lawn cover produced in an intensively managed agricultural operation (i.e., sod farm), removed intact with a minimal amount of soil, and transplanted to another location. Mature turfgrass sod is carefully and professionally cultivated, cut into squares or rolls with the underlying soil and roots, and shipped to a nursery or job site to be replanted. Turfgrass can also be established and maintained by vegetative propagation using pregrown plugs or by direct seeding. Common turfgrass species grown in the United States include Bermuda grass, centipede grass, fine fescue, Kentucky bluegrass, ryegrass, St. Augustine grass, tall fescue, and zoysia grass. Each grass has advantages and disadvantages: Some like shade, some require lots of water, and some are wear-resistant, and golf courses

often use a number of species to maintain various parts of their fairways, greens, collars, and so forth. Turfgrass selection, cultivation, and maintenance are the most highly scientific and technically demanding parts of maintaining a playable golf course.

Usually, turfgrass sod cultivation is a local business within 150 miles (241.4 km) or so, as climatic conditions must be similar in the growing and planting areas. Turfgrass sod is classified in two general categories, cool-season grasses such as bluegrass and tall fescue and warm-season grasses including Bermuda grass and zoysia grass. Cool-season grasses grow best in the northern parts of the United States, as well as in areas with higher elevations and coastal regions where evening summer temperatures are in the 50–60°F (10–16°C) range. Warm-season grasses are usually grown for use in southern Florida, along the Gulf Coast, and throughout the Upper South.

Once a golf course has selected a turfgrass or, more likely, the several species of turfgrass that it will be using, the expensive plantings must be maintained and cultivated. Maintenance is done through the use of fertilizers and pesticides. Fertilizers are needed to ensure that turfgrasses remain healthy under the heavy use they receive during playing times and seasons on the course. The primary fertilizers needed by turfgrasses are similar to those of most plants, nitrogen (N), phosphorus (P), and potassium (K). These three elements are essential plant nutrients, and growth is not possible unless sufficient quantities are available. Nitrogen is an essential component of all proteins, and, as a part of the deoxyribonucleic acid (DNA) molecule, it is essential for both growth and reproduction. Plant stunting is a common symptom of nitrogen deficiency. Phosphorus is needed by plants for the conversion of light energy to chemical energy, adenosine diphosphate (ADP) to adenosine triphosphate (ATP), during photosynthesis. It is essential for plant growth and flower/seed formation. Potassium regulates the opening and closing of plant stomata, the pores on the underside of the leaf used for gas exchange and in moisture regulation. Without sufficient potassium, the plant is unable to regulate the amount of water it takes in or loses. Potassium deficiency may cause necrosis (cell death) or interveinal chlorosis (loss of color).

Nitrogen as N is not bioavailable and must be supplied to plants and animals in another form, as either nitrate (NO<sub>3</sub>) or ammonia (NH<sub>4</sub>). The same holds true for phosphorus, which is usually chemically combined with oxygen to form phosphate (P<sub>2</sub>O<sub>5</sub>), and potassium,

in the form of KCl or potassium chloride. Fertilizers are the commercial end products of these chemical combinations and are expensive to purchase and expensive to apply, requiring the use of specialized equipment and trained personnel. A major objective of a well-founded fertilizer management program is to supply these essential plant nutrients at the proper time and in the proper amount to support plant growth and development, with no excess. Excessive quantities of nitrogen and phosphorus only result in excessive weed growth and possibly turf disease, rusts, and burns, but also can contaminate groundwater and surface water.

Excess fertilizers are removed from golf courses in two ways: in surface water or in groundwater. Fertilizer that is not taken up by plants can be washed by rainfall into the local drainage system and eventually into the regional watershed. Nitrogen poses particular problems as a component of fertilizer because it can cause surface water eutrophication. This condition occurs if lakes, estuaries, or slow-moving streams receive excess nitrogen and phosphorus. As they do on land, these nutrients stimulate excessive aquatic plant growth (algae and periphyton). This enhanced plant growth, often called an algal bloom, leads to reduced dissolved oxygen levels in the water when bacteria consume the dead plant material. It can lower dissolved oxygen levels needed by more developed organisms, such as fish. Algal blooms also decrease the amount of sunlight penetrating the water and reduce viable habitat for many near-surface plant and animal species.

Nitrogen and phosphorus can originate not only from golf course runoff, but also from many other sources such as agricultural fields, suburban lawns, and sewage treatment plant discharges. Water with a low concentration of dissolved oxygen is called hypoxic (low oxygen) and has a dissolved oxygen concentration of less than 2 ppm. Water fully saturated with oxygen has a dissolved oxygen concentration of 12 ppm.

If excess nitrogen enters the groundwater via leaching, it can have a disastrous consequence on public health. The maximal level for nitrogen in water is set at 10 mg/L by the U.S. Environmental Protection Agency. This regulatory limit was developed in order to protect babies and infants whose immature digestive systems contain a type of bacteria that change nitrate ( $\text{NO}_3$ ) into nitrite ( $\text{NO}_2$ ). The nitrite reacts with hemoglobin, which carries oxygen to all parts of the body, to form methemoglobin, which does not carry oxygen. As the level of methemoglobin increases, depending on the amount of nitrate

ingested and converted, the amount of oxygen being carried throughout the body decreases. Eventually, blood oxygen levels fall to below life-sustaining concentrations, and the baby suffocates. This condition is called methemoglobinemia, or blue baby syndrome, because the most obvious symptom of nitrate poisoning is that the skin turns a bluish color, particularly around the eyes and mouth. The blood sample of an affected baby is chocolate brown instead of a healthy red. Nitrate poisoning can be treated, and in most cases the baby makes a full recovery. Around the age of three months, an increase in the amount of hydrochloric acid in a baby's stomach kills most of the bacteria that convert nitrate to nitrite. By the time the child is six months old, its digestive system is fully developed and none of the nitrate-converting bacteria remain.

Pest management is another way that golf courses can adversely affect local water quality. To protect their turfgrass investment and to maintain playable fairways and greens, most golf courses use agricultural chemicals in the form of pesticides to help control weeds and vectors. If properly stored, mixed, and applied, turfgrass pesticides, when used in combination with other insect management techniques—biological controls, such as establishment of habitat for insect predators; and mechanical controls, such as traps and buffer zones, among others—can have a minimal impact on surface water and groundwater quality. Overuse of pesticides, however, or their improper application or storage, has resulted in the contamination of groundwater underlying golf courses.

There are three types of commonly used pesticides on golf courses: Fungicides such as iprodione, chlorothalonil, and anilazine to kill fungi; herbicides such as bensulide 2, 4-D acid (Trimec) and mecoprop sprayed on turfgrass to control weeds; and insecticides, which include carbaryl, chlorpyrifos, and bendiocarb. Many of these and other pesticides are known or suspected human carcinogens, and exposure to them can have serious health consequences. Fortunately, many characteristics of pesticides that make them useful turfgrass management tools also make them fairly immobile. These properties include a tendency to "stick" to plants and insolubility in water, among others. Studies by both the U.S. Geological Survey and U.S. Golf Association have found that groundwater quality underlying most golf courses has been only minimally affected by pesticide applications. Even the widespread use of pesticides at 52 golf courses on

*(continues)*

(continued)

Long Island, New York, at very high levels, 18 pounds (8.16 kg) per treated acre, has not resulted in widespread contamination of underlying groundwater supplies. Currently, golf course operators and groundskeepers on Long Island and across the United States are well aware of the possible environmental damage that can be caused by the improper use of these dangerous chemicals and have implemented programs to limit their application and improve their effectiveness.

Other types of environmental impacts from golf courses are those that commonly are associated with related commercial activities. These include releases of petroleum products from underground tanks used to store maintenance vehicle fuels; improper disposal of used oil, antifreeze, and lead acid batteries from golf carts; and discharge of untreated wash water and equipment rinsate containing oil, grease, fertilizer, and pesticide residues. Most golf courses have established special storage and washing areas that are designed to isolate and contain these types of materials from the environment. Equipment washing and container rinsing, for example, are done on a concrete pad where wastewater is diverted to a sump and then pumped into a holding tank for later pickup and disposal. Underground storage tanks at golf courses are subject to the same regulations and upgrades for spill containment and leak detection as those at any gas station.

Many golf courses have developed integrated pest and fertilizer management plans, procedures that utilize a variety of techniques that help minimize agricultural chemical applications. These include setting threshold levels to identify when and where pest populations or turfgrass condition require action. In other words, the presence of a single bad bug or brown patch of grass may not require the application of pesticides and fertilizers across the entire course. Regular monitoring of course agriculture also is done so that chemical applications can be tailored to turfgrass conditions, rather than being performed on a routine basis. Different horticultural methods also

are used, such as selecting pest-resistant varieties of turfgrass and planting pest-free rootstock. These methods can be effective and cost-efficient while not presenting a risk to people or the environment. Finally, when an application of agricultural chemicals becomes necessary, substances that present the least public health and environmental risk can be chosen. Examples include highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring indicates that these less risky controls are not working, then targeted spraying of pesticides can be followed by broadcast spraying of nonspecific pesticides as a last resort.

*See also* EUTROPHICATION; LEAD; NITROGEN; PESTICIDES; PHOSPHORUS; UNDERGROUND STORAGE TANK.

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by Robert P. Blauvelt

they basically remain where they are deposited until they are physically moved or diluted with clean soil.

### ORGANIC POLLUTANTS

Organic contaminants are introduced into soil by leaks in manufacturing, transportation, and storage; air pollution fallout and washout; spraying; and direct dumping. They are universally less persistent than the heavy metals and degrade in as little as a

few hours to as much as several decades, in most cases. Many are susceptible to biodegradation and alteration, and they contain carbon compounds that can be used for energy. Organic pollutants are far more abundant than inorganic pollutants. In short, virtually every person has contact with some organic pollutant every day of his or her life.

The organic compounds that are purposefully sprayed or applied to soil are mainly used for agricultural and landscaping purposes. These pollut-

ants are pesticides, herbicides, and fertilizers and are probably the most damaging of all pollutants to the environment. Most are very soluble and can be readily leached into the groundwater system and are found in drinking water supplies throughout the country. Some may be adsorbed to clay or organic particles and remain fixed. These are the most persistent of the organic compounds. Some pesticides are so potent that they are even toxic to the microorganisms in the soil and must be broken down by chemical reactions. They add even more persistence. Some pesticides are designed to be systemic and are absorbed into the root system and distributed throughout the plant. Fertilizers and pesticides can be washed from the soil in surface runoff and transported to surface water systems. They can have devastating effects on these systems as well.

There are huge amounts of organic pollutants in the air from numerous point and nonpoint sources. Probably the most abundant is from automobile exhaust, evaporation of volatile organic compounds, and other burning. Most of these organic pollutants remain in the air until they are degraded. Some, however, are washed out in precipitation and enter the soil system. Soot settles to the ground by gravity and can cause problems if there is enough, but most is readily absorbed into the soil system and degraded by microorganisms.

Leaks of organic compounds into the soil are very common. The majority of these leaks are from underground storage tanks (USTs). The most frequent of these leaks are at gasoline stations and home heating oil tanks. The contamination from them largely affects groundwater, but the pollutant must pass through soil to reach the water table. The plume really rides on top of the water table and infiltrates soil through the entire migration. As it does, it leaves behind petroleum, coating the particles and filling small pores. In this way, the soil is also contaminated. The same leaks can occur in pipelines and manufacturing facilities.

Direct and deliberate dumping of organic pollutants produces a very dangerous site. Some of the most troublesome Superfund sites involve industrial organic pollutants. An example is the 200-mile (320-km) stretch of the Hudson River in New York State. General Electric dumped huge amounts of polychlorinated biphenyls (PCBs) into the river during the middle part of the 20th century. Although it primarily affects river sediments, it also affects soils along the river. Two of the largest cases of organic soil pollution and two of the most important polluted sites in the world are Love Canal, New York, and Times Beach, Missouri. There are

many others in which the pollution of soil is the most important impact.

Soil pollution is a grave danger to the very survival of the human race. Soil produces the vast majority of the food we consume whether directly or indirectly as feed for livestock. As humans attempt to squeeze every drop of productivity out of agricultural lands, there are risks of catastrophic collapse. There have been examples in the past of soil mismanagement that threatened to restrict productivity such as the dust bowl of the American Midwest as well as numerous cases of desertification around the world. There have been numerous individual cases of soil pollution that rendered large areas ecologically dead, primarily from mining and smelting operations. The areas around Norilsk, Russia; Sudbury, Canada; Ducktown, Tennessee; and Palmertown, Pennsylvania, are just four examples of such disasters, and there are many more. Fortunately, society has realized the danger of these situations and taken deliberate actions to prevent them from continuing and to remediate the problems. It is a credit to the human race that they have understood the value of productive soil in these cases and have taken steps to address many of the other problems as well.

See also AIR POLLUTION; ARSENIC; CADMIUM; CHROMIUM; INORGANIC POLLUTANTS; LEAD; MERCURY; NORILSK MINING POLLUTION; ORGANIC POLLUTANTS; SOIL; SUDBURY MINING AND AIR POLLUTION; WATER POLLUTION; ZINC.

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### **Southern Crop Services Delray Beach, Florida (1988–2008) Soil and Water Pollution**

There are few movie scenes more memorable than the classic 1959 Alfred Hitchcock thriller *North by Northwest*, when Cary Grant was chased into a dried cornfield and covered with pesticides by a buzzing World War I vintage biplane. Crop dusting, also known as aerial application, is the method by which fungicides, pesticides, and herbicides are dispersed onto crops or cropland from an airplane or helicopter. Fertilizing, or top-dressing, and seeding also have been done from airplanes, especially in areas where more traditional methods are difficult, such as hillsides and marshy soil. One of the first documented uses of aerial seeding was in 1906, when a tethered balloon was used to spread seeds over a swampy patch of ground in New Zealand.

It was in 1921, when a surplus Curtiss JN-6H biplane, the Jenny, with a metal drum strapped to its undercarriage and piloted by a U.S. Army Air Service officer, that crop dusting began in earnest. Flying just above a fruit orchard that was being devoured by *Catalpa sphinx* moths near Troy, Ohio, Lieutenant John MacReady pulled a lever mounted just outside the cockpit and discharged a load of powerful lead arsenate insecticide that ended the infestation within a few hours. This act founded the new industry of crop dusting, which would play a pivotal role in American agriculture. The Delta Dusters Company started out providing aerial application services and evolved into a major airline.

Aerial application expanded greatly after World War II, with a large number of pilots and surplus planes available. This expansion was aided by the interest of the American farmer in applying organophosphate and organochlorine pesticides. Crop dusting planes became more sophisticated, and eventually the Piper Pawnee, a specially designed low-wing monoplane with a high cockpit for increased visibility and anticorrosion features in its fuselage to protect against chemical damage, emerged as the plane of choice for aerial application. Other models with similar features such as Cessna's Ag-Wagon and Grumman's Ag-Cat also were widely used.

### **POLLUTION OF THE SITE**

Riding this wave of pesticide use was a company called Southern Crop Services, or SCS. Founded in the late 1940s in Delray Beach, Florida, about 20 miles (32 km) south of Palm Beach, SCS operated as an aerial application service until 1992, with a name

change in the mid-1980s to King Aerial Service. Not much to look at, the 30-acre (12.1-ha), grass-covered property occupied by SCS included a runway with a few small trailers at one end and a drainage ditch along its eastern boundary. Major parts of SCS's operations were the mixing and storage of the pesticides that were loaded onto the wing and belly tanks of its planes, and it was these activities that eventually converted this nondescript airfield into one of eastern Florida's most notable hazardous waste sites.

When pesticides are shipped from the manufacturer to the customer, they are often transported as a concentrated solution or a dry powder. Prior to application, they are diluted and/or mixed with a solvent. Typical solvents are water, kerosene, or some fluid that evaporates readily or even a separate agent or compound to increase its effectiveness. Today, pesticide mixing is done on well-ventilated, concrete pads that are surrounded by curbs or have other types of secondary containment that reduce the chance that spills will enter the soil or groundwater system. In the 1940s and 1950s, however, such protection was not common, and pesticide mixing and storage areas on farms, ranches, and airports were common sources of soil and groundwater contamination.

In addition, when airplanes returned from an aerial application, their pesticide storage tanks were cleaned or rinsed before being reloaded, especially if a different product was going to be used. These pesticide-rich wash waters were discharged onto the soil or into a drainage ditch or pond and allowed to seep into the ground, causing local and sometimes widespread environmental effects. Occasionally, aircraft returned with surplus pesticide in their tanks that was emptied or purged with compressed air or high-pressure water onto an unpaved area or ditch near the runway. This waste contaminated both the soil and the groundwater.

These types of practices at SCS and other aerial application companies across the United States were commonplace and resulted in on-site contamination, primarily by the discharge of pesticide rinsates from mixing vats and aircraft spraying systems into a shallow on-site disposal lagoon or directly onto the ground. SCS also buried drums and other types of containers that had contained pesticides, and leakage from pesticide drums into the soil and groundwater system further contributed to the contamination.

By 1977, the 8,400-cubic-foot (238-m<sup>3</sup>) unlined lagoon that SCS had been using for pesticide tank rinsates and discarded chemicals was full, and there were reports of its overflowing and washing onto an adjacent property. In August 1983, the Palm Beach County Health Department directed SCS to stop using the lagoon and to conduct a contamination

assessment of its property. The study was completed in early 1984. It revealed that pesticides including toxaphene, dichlorodiphenyltrichloroethane (DDT), DDD, and parathion and heavy metals including arsenic, zinc, and copper were detected in soil and shallow groundwater in the area near the lagoon. SCS made an early attempt at cleanup, excavating sludge in the lagoon and stockpiling it on-site for later disposal, but the magnitude of the problem quickly overwhelmed the resources of this small company.

### THE CLEANUP

Using a risk-based approach, the Florida Department of Environmental Regulation (FDER) established a surface soil (upper 24 inches [61 cm]) cleanup criterion for SCS of 50 parts per million (ppm) of toxaphene. This meant that soil at the surface containing this concentration of toxaphene or less could remain on-site and not cause an unacceptable public health risk. The 50-ppm concentration also did not pose a threat of groundwater contamination. FDER later established a risk-based level of 100 ppm toxaphene for subsurface soil (deeper than 24 inches [61 cm]). On the basis of previous site studies, it was determined that at least 3,000 cubic yards (2,294 m<sup>3</sup>) of soil was present at the site that contained 50 ppm or more of toxaphene. Chlorine- and phosphorus-based pesticides were found at similarly high levels. Toxaphene also was detected in a groundwater sample from an on-site supply well.

The U.S. Environmental Protection Agency (EPA) and FDER became impatient with the slow pace of SCS's remedial response, so in 1988 and again in 1990, they initiated their own program of soil/sludge and lagoon water disposal. In 1988, acting at the request of FDER, EPA excavated approximately 4,800 tons (4,355 metric tons) of soil and sediment that exceeded the toxaphene cleanup standard. These materials were treated on-site by a high-temperature thermal desorption incinerator. Clean ("roasted") soil then was redeposited at the site. EPA also treated more than 300,000 gallons (1.1 million L) of contaminated lagoon water. Treated water was discharged into a local drainage channel.

With regulatory pressure mounting for more aggressive remedial actions, SCS accepted the inevitable and signed a consent order with FDER to sell the property. The proceeds were to be used for both cleanup and reimbursement of FDER for its investigation and enforcement actions. The process took almost 10 years, but the site was subdivided and sold in 1996 to two real estate development firms.

A second removal action took place in May 1990; it resulted in the excavation and off-site disposal of

approximately 540 tons (490 metric tons) of contaminated sediment from the on-site lagoon. Another 250,000 gallons (946,353 L) of lagoon water was treated by carbon absorption to below detection limits (less than one part per billion [ppb] DDT) and then discharged to a nearby drainage channel.

Although the FDER and EPA interim remedial actions addressed the most seriously contaminated parts of the site, residual amounts of soil are still present, both on- and off-site, that are greater than state cleanup levels for unrestricted use. In addition, groundwater monitoring has indicated that low levels of arsenic and pesticides in the shallow water-bearing zone remain present in isolated areas on the SCS property. Fortunately, water supply wells in a residential area east of the site have not been affected. The problem was that the clean private wells precluded the SCS site from inclusion on the National Priorities List as a Superfund site and, therefore, federal money was not available to fund the rest of the cleanup.

By 2007, an estimated 35,000 tons (31,752 metric tons) of contaminated soil still needed to be removed, including off-site contaminated soil. This removal was to be completed by 2008, but implementation was complicated by the presence of nearby wetlands, which had to be protected during excavation activities. Once affected soil has been removed, FDER anticipates further reductions to approved cleanup levels in the arsenic and pesticide concentrations that have been found in the shallow water-bearing zone. Groundwater monitoring will continue after soil remediation to verify that this is occurring.

*See also* ARSENIC; DDT; INORGANIC POLLUTANTS; IN SITU GROUNDWATER REMEDIATION; LEAD; PESTICIDES; SOIL POLLUTION; SUPERFUND SITES; TOXAPHENE; PHOSPHORUS; ZINC.

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### space shuttle launches and air pollution

The *Saturn V* rocket, the largest ever built and operated by the National Aeronautics and Space Administration (NASA), successfully launched the Apollo Moon missions and the Skylab Space Station, and it continues to lift the space shuttle into orbit around the Earth. When the fuel in the *Saturn V* is ignited, it forces a massive, continuous thrust of hot gases downward through its vents and portals. This downward force results in an equal and opposite push of the rocket upward. Current space vehicles operate on a linear, multistage design. A single-stage-to-orbit (or SSTO) vehicle that can achieve orbit without discarding fuel tanks or motors is being evaluated by NASA. SSTO vehicles, which also would be reusable,

may be less expensive to launch and operate, although more expensive to design and build.

### TYPES OF ROCKET FUEL

The rockets and their fuels are stacked on top of each other, with the first stage the largest and having the heaviest fuel. When the first-stage rocket's fuel is exhausted, it is detached with a small explosive charge from the space vehicle and the second-stage rocket is fired. After the second-stage rocket's fuel is gone, the third stage is fired, and so on. By jettisoning the empty fuel tanks and associated rocket motors, the now-much-lighter spacecraft requires less fuel to reach its mission or orbital velocity and altitude. In addition, fuel selection can be optimized for its operational atmosphere.

The power, efficiency, and environmental impact associated with the use of rocket fuel are dependent



upon its chemical composition. NASA, the military, and commercial launch organizations generally rely on four types of propellants:

**Petroleum.** This type of rocket fuel is highly refined kerosene called RP-1 (refined petroleum). Rocket fuels need to provide their own oxidizer, and RP-1 is usually combined with liquid oxygen (LOx) and burned to create thrust at low altitudes. RP-1 is a fossil fuel, and its combustion products include carbon dioxide, sulfur and nitrogen oxides, and particulate matter.

**Cryogenics.** These types of propellants are a fuel mixture of liquid hydrogen (LH<sub>2</sub>) and liquid oxygen. Both components are liquid at only very low temperatures (hundreds of degrees below zero), but cooling and compressing them allows large amounts to be stored in appropriately sized containers. If they were left in their gaseous forms, huge fuel tanks would be needed to store sufficient amounts of hydrogen and oxygen to launch a spacecraft or missile. Cryogenic fuels are lighter and have about 40 percent more power by weight than petroleum or solid rocket fuels. The *Saturn V* second- and third-stage rockets are cryogenically fired and are used to insert the space shuttle into Earth orbit. The end product of this combustion process is water, making cryogenic fuel very environmentally friendly.

**Hypergolics.** Thrust from this type of propellant occurs as fuel of monomethyl hydrazine (MMH), or hydrazine, and oxidizer of nitrogen tetroxide (N<sub>2</sub>O<sub>4</sub>) ignite during mixing, requiring no ignition source. One of the major advantages of hypergolics is that they can be stored at ambient temperatures and pressures and the reaction can be started and stopped by simply shutting off the flow of either the oxidizer or the fuel. MMH and N<sub>2</sub>O<sub>4</sub>, however, are dangerously toxic and must be managed by highly controlled safety procedures. Hypergolics power the space shuttle's orbital maneuvering, attitude control, and reentry systems.

**Solids.** Also called solid rocket boosters (SRBs), these are the oldest rocket fuels, first developed in ancient China. Fuel and oxidizer are loaded into a steel shell and ignited to provide thrust. For the space shuttle, the oxidizer is ammonium perchlorate, and the fuel is a form of powdered aluminum. A third ingredient, polybutadiene acrylic acid acrylonitrile, binds the mixture. Initially a liquid, SRB is cured into a soft, rubberlike solid. Stable and easily stored, SRBs do not require complex propellant-feed systems and often are used to provide additional thrust during launch or during the final stages of a launch. The space shuttle uses the largest solid

rocket motors ever built with each reusable booster containing more than 1 million pounds (454,000 kg) of propellant, supplying almost 2.7 million pounds (1.2 million kg) of thrust. The majority of military rockets (intercontinental ballistic missiles [ICBMs], such as the Minuteman and Peacekeeper) also use solid rocket fuels.

## ENVIRONMENTAL EFFECTS OF ROCKET LAUNCHES

Space shuttle launches, as well as other types of space exploration or military rocket testing and development, produce adverse environmental effects. Most of the emissions that are seen during a space shuttle launch are water vapor or steam mixed with very minor amounts of combustion products. At 11 seconds before the main engines fire, a storage tower near the launch pad begins to discharge about 900,000 gallons (3.4 million L) of water from six large nozzles into a trench just beneath the launch pad. This water continues to flow for about 20 seconds after main engine ignition and acts as an acoustical barrier and flame deflector, protecting the shuttle from the noise and heat generated by the SRBs during a launch.

The exhaust gases from the SRBs, which provide about 70 percent of the launch thrust for the space shuttle, contain very small amounts of chlorine. This chlorine combines with water vapor to form hydrochloric acid mist, which has caused some damage to wetlands and plants near the launch pad. NASA tries to mitigate these effects by launching when local winds blow this mist out to sea, where it is quickly neutralized by seawater.

As the space shuttle climbs into orbit, exhaust gases released into the thermosphere, the outermost layer of the Earth's atmosphere, settle and condense into a cloudlike layer of ice crystals. This layer, which has been detected in the sky over the Arctic, results in a "night-shining," or noctilucent, cloud, one that is not visible until the Sun's rays reflect off it from below the horizon. Although this small amount of additional water vapor is not likely to have an impact on either Arctic or worldwide atmospheric conditions, its presence is illustrative of the need to be alert to the environmental consequences of rocket launches.

Of more immediate concern is perchlorate, one of the primary components of SRB fuel. Perchlorate has been detected in groundwater and soil samples from more than 40 states. If ingested, perchlorate interferes with iodine uptake in the fetus, young children, and adults. The U.S. Environmental Protection



Agency is currently considering adding perchlorate to the list of chemicals that must be tested for under the Safe Drinking Water Act. California, Arizona, Nevada, and other states that have hosted significant amounts of rocket tests and launches are especially concerned over the presence of this compound in their local environments and its potential impact on public health.

On a global scale, about 11,000 tons (10,000 metric tons) of rocket propellant is burned in the atmosphere annually from both civilian and military sources. The release of chlorine, free radicals, and aerosols as a result of these launches, particularly those using SRB and hypergolic fuels, may be contributing to destruction of the ozone layer. Although the amounts of potentially ozone-depleting substances released by this activity are relatively small on an international scale, approximately 130,000 tons (117,900 metric tons) of ozone-depleting products was manufactured worldwide in 2003. They are, therefore, not insignificant, and part is delivered directly to the stratosphere, where they do the most damage.

The technologies to launch rockets into space were developed at a time when political and military agendas were the driving forces. Technological dominance over the Soviet Union far outweighed the environmental consequences on the American agenda. Those attitudes have changed in recent years, and space exploration must become more environmentally responsible in line with public opinion. Environmental Impact Statements are required before a new or expanded launch program can be initiated, and these programs must include measures to reduce or minimize both ecological and atmospheric effects. Extensive research is being done to find a cheaper, safer, and less environmentally damaging replacement for hydrazine-driven thrusters. Ion engines and electric propulsion systems are the leading candidates, along with short-term fuel combination changes that provide some environmental benefit through the more efficient mixing and matching of propellant types.

See also AIR POLLUTION; LAUNCH COMPLEX 34; OZONE AND CHLOROFLUOROCARBONS; PERCHLORATE.

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**streams** Streams are bodies of surface water that flow in channels, thereby draining water from higher to lower elevations. They may contain water from surface runoff both directly from precipitation and from the melting of stored precipitation in snow and ice. They may also contain base flow from groundwater directly infiltrating into the stream from springs. The proportion of these two components, base flow and surface runoff, varies considerably, depending upon the stream, season, climate, and other factors. Streams originate at their headwaters, where small tributaries in the drainage basin coalesce to form a larger stream or river. Streams are ranked according to their position relative to the river, which is considered a first-order stream. Tributaries feeding directly into a river are second-order streams, which are, in turn, fed by third-order streams.

The drainage pattern of the rivers and tributaries commonly reflects the underlying rock and soil units. In map view, a dendritic drainage pattern looks like the branches on a tree and reflects horizontal strata. A trellis drainage pattern contains tributaries that are generally straight and parallel but periodically contain right-angle turns. This pattern indicates tilted strata. There are several other patterns, which are less common.

Streams reflect the relative ruggedness or "age" of the topography through which they flow. Immature, rugged topography produces fast-flowing "young" streams in steep valleys and canyons, whereas mature, flat topography produces slow-flowing "old" winding streams in wide flat floodplains. There are also "middle-aged" streams, which fall between the two. The age of the stream really has no relation to its condition. A single stream may have "young" characteristics in its headwaters, "middle-aged" features in the midsection, and "old" features near the mouth. There are two end member types of streams that are common and characteristic. Generally, young streams are braided streams and old streams are meanders.

### BRAIDED STREAMS

As is illustrated by the name, the channels in a braided stream form a braided, or anastomosing, pattern. The channels surround lozenge-shaped channel bars of sand and gravel. During the summer and times of low rainfall and runoff, the channel bars are land surrounded by the thin channels filled with relatively gently flowing water. Discharge is low, as are velocity and sediment load. The bars remain relatively fixed with only minor winnowing of sand from the upstream end of the bar and deposi-

tion on the downstream end. Vegetation may even occur on the channel bars during this period.

During spring thaw or heavy rains, these streams become raging torrents with high velocities, discharges, and sediment loads. The river levels rise to the point that all channel bars are submerged. All sizes of sediment are transported, and rapid downstream migration and reshaping of the channel bars take place. All vegetation and structures that colonize the channel bars during the low-flow times are washed away during these times.



Deep Creek estuary near Broome, Australia, is an example of how yellow sand, carried by winds from the mainland, and gray silt collect in the estuary, narrowing the river's path. (Bernhard Edmaier/Photo Researchers, Inc.)



## COLORADO RIVER

One of the most tightly managed and hotly debated watersheds in the United States is the Colorado River. Flowing through Wyoming, Colorado, Utah, Arizona, Nevada, California, New Mexico and northern Mexico, the Colorado River has provided its resources for almost 800 years. Early Native Americans developed a sophisticated canal system to distribute water. These canals were later cleared and used by the first European settlers in the 1860s. The

drainage basin of the river is 244,017 square miles (632,000 km<sup>2</sup>) but is not heavily populated, containing only three cities, Las Vegas, Phoenix, and Tucson, with populations greater than 50,000 residents. Considering the images of the wild river and the increasing number of people that it serves, it is surprising that the annual flow is only about 3 percent that of the Mississippi River and 10 percent that of the Columbia River. The arid climate and burgeoning population of the Colorado River watershed, however, make the water a more valuable resource than water in other areas, leading to many decades of conflict on a national to international basis and severe deterioration of water quantity and quality. Lacking a standardized set of pollution controls or water use criteria, each state and Mexico has sought to exploit the Colorado River for its own purposes, without regard to effects on downstream users.



**Map of the southwestern United States showing the Colorado River drainage basin**

### WATER USE CONFLICTS

Issues of water quantity are clearly the main concern in the Colorado River drainage basin. Several dams have been built along the river, including the famous Hoover Dam, to control water supplies. Water is piped out from these areas as far away as Los Angeles and the Imperial Valley of California. Usage is so heavy that in some years the river runs completely dry at its mouth and no water empties into the Gulf of California. This severely alters the ecology and sediment dynamics of the area. The level of conflict over water has escalated to near-wars, in some cases, and the potential for further conflict is very high. One of the fundamental bases for these conflicts is that water allocation rights were determined on absolute quantities (total gallons) that were measured during several uncharacteristically wet years, rather than

Braided streams occur in areas of rugged topography. They have steep valley walls, narrow floodplains, and generally straight courses. The volume of water varies greatly throughout the year, yielding a very large range for the river level. The valley walls are so steep, however, that lateral spreading of the stream during flood stage is minimal.

### MEANDERING STREAMS

Streams with highly sinuous channels that meander across the countryside as they make their way to the sea are called meanders. These channels are con-

stantly shifting across the wide floodplain that characterize meanders. The water in the stream flows straight so it strikes the bank on the outer arc of the curved channel, undercutting and eroding it. This is called the cut bank, and its erosion allows the channel to migrate slowly in the flow direction. On the opposite, inner arc bank, the stream experiences a much slower flow velocity. As the flow velocity drops, the stream can no longer carry sediments, and they deposit on the point bar that lines the inner arc. This process of erosion on one bank and deposition on the facing bank occurs continuously and accommodates the slow migration of the channel.

as a percentage or proportion of flow. Now, if a sustained dry period or prolonged drought occurs, flow rates along the entire river will decrease and there could be severe water shortages.

The plethora of court decisions, federal legislation, interstate agreements, and even an international treaty have come to be known as the law of the river. Two of the important early documents in Colorado River watershed management are contained in the Colorado River Compact of 1922, which divided users' withdrawal water rights between an upper basin and a lower basin. A treaty with Mexico in 1944 required the United States to deliver 325,829 gallons (1.85 km<sup>3</sup>) of water annually to Mexico. It took a U.S. Supreme Court decision in 1963 to settle a long-standing conflict over water appropriation between Arizona and California, the latter of which lost the decision and had to relinquish 130,332 gallons (0.74 km<sup>3</sup>). The Colorado Basin Salinity Control Act was approved by Congress in 1974. It was passed to prevent an increase in the salinity of river water because of overuse and prevented the construction of a desalination plant.

### POLLUTION OF THE RIVER

The Colorado River has pollution issues that are both common and uncommon. The common problems occur around the few cities along the river, where sewage overflow and other anthropogenic input degrade the quality of the water. The expanding recreation area around Lake Mead near Las Vegas, through sport activities on the lake and development along the shores, also degrades the quality of the water. The pollution problems that are uncommon include turbidity and salinity of the water. The lack of vegetation along the banks of the river and abundance of fine loose sediment within the watershed result in a heavy amount of fine particulate in the

river water. More may be added by direct erosion, surface runoff, or wind. This turbidity is especially an issue along stretches of the river where flow is rapid because it quickly deposits silt and fills in the area behind the dams. The arid conditions of the Colorado River basin produce very high evaporation rates. More evaporation causes an ever-increasing proportion of dissolved salt compounds. Although this is an issue all over the river, in flowing areas, the constant mixing reduces the impact of evaporation. Where the river is dammed, however, the length of time the water remains behind the dam, its residence time, is long, often measured in months or even years, and the amount of mixing that occurs between newly arrived water and water that has been present behind the dam for a long time is not significant. These factors lead to very high salinities in several areas along the river to the point where desalination procedures are necessary to make the water potable.

*See also* AQUIFER; POINT SOURCE AND NONPOINT SOURCE POLLUTION; STREAMS; WATER POLLUTION.

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by Alexander E. Gates

Channels may also shift quickly in a process called avulsion. This can occur in one of two ways: neck cutoff or chute cutoff. When two channel loops in a meander belt slowly migrate toward each other, at some point they collide. At this point, instead of traveling around these large loops, the stream takes the shortest route to the ocean, abandoning the old channels. Water remains in these old channels, forming oxbow lakes along the sides of the active stream. Eventually, these lakes fill with sediment through weathering and erosion of the banks. Chute cutoff is also a channel abandoning process but occurs during floods. There is an overflow channel on the point

bar side of the meander loop. This overflow channel or chute makes a much shorter and straighter path than the main channel. During floods, the stream overflows the banks and floodwater flows through the chutes to help drain the extra water. If the flood is especially high, erosion of the shoot may be so deep that the entire stream shifts to the chute and abandons the main channel. An oxbow lake forms by this process, as well.

The topography is so flat around meander belts that flooding is common. When the stream overflows the river banks, velocity abruptly slows and sediments deposit on the bank edge. These deposits form narrow



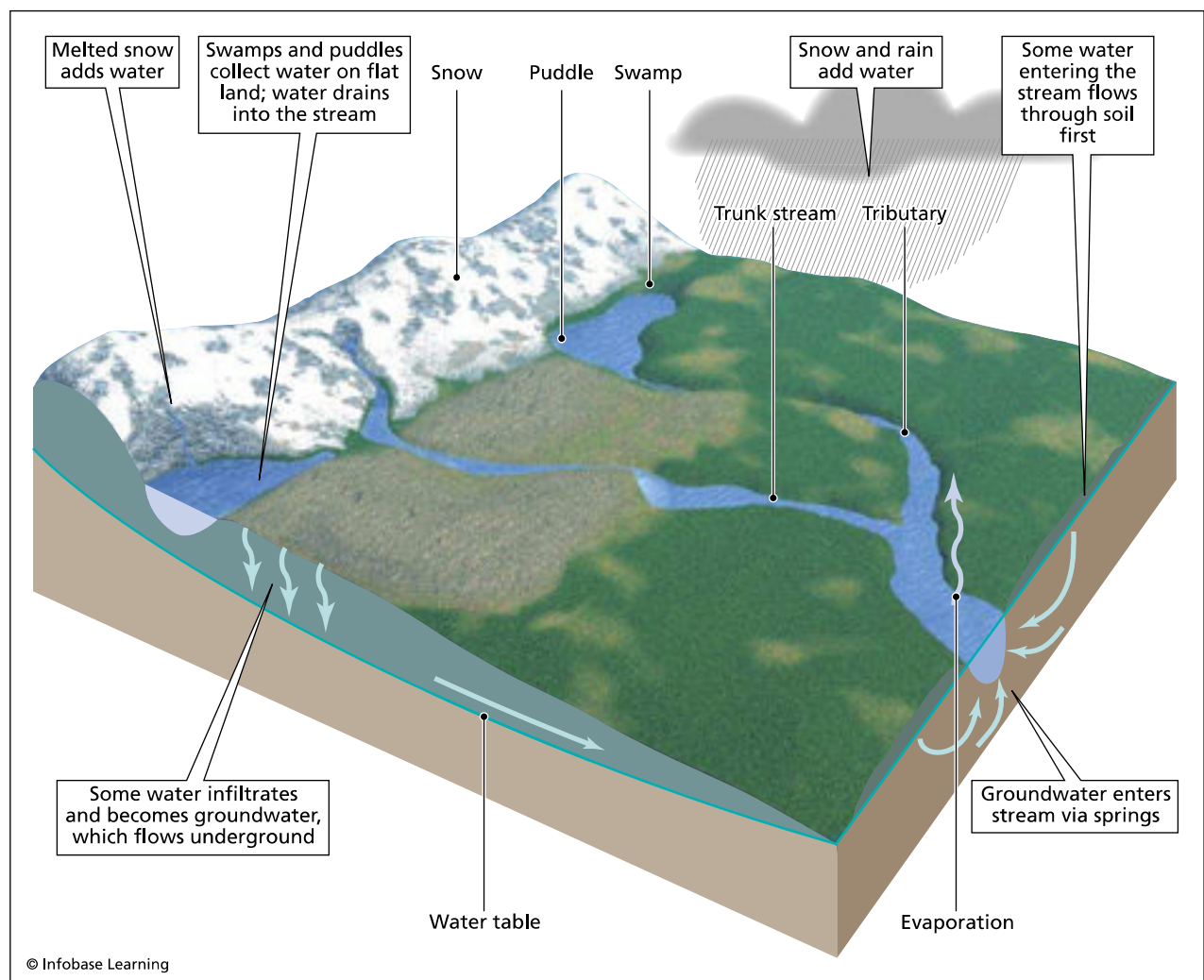
mounds all along the stream course, called natural levees. They help to keep the stream in the channel and are commonly reinforced to reduce flooding. Flooding can be extremely destructive in meander belts because the large area of flat topography allows the stream to spread across a wide area. It is for this reason that these areas are extensively managed and become large-scale U.S. Army Corps of Engineer projects.

### POLLUTION OF STREAMS

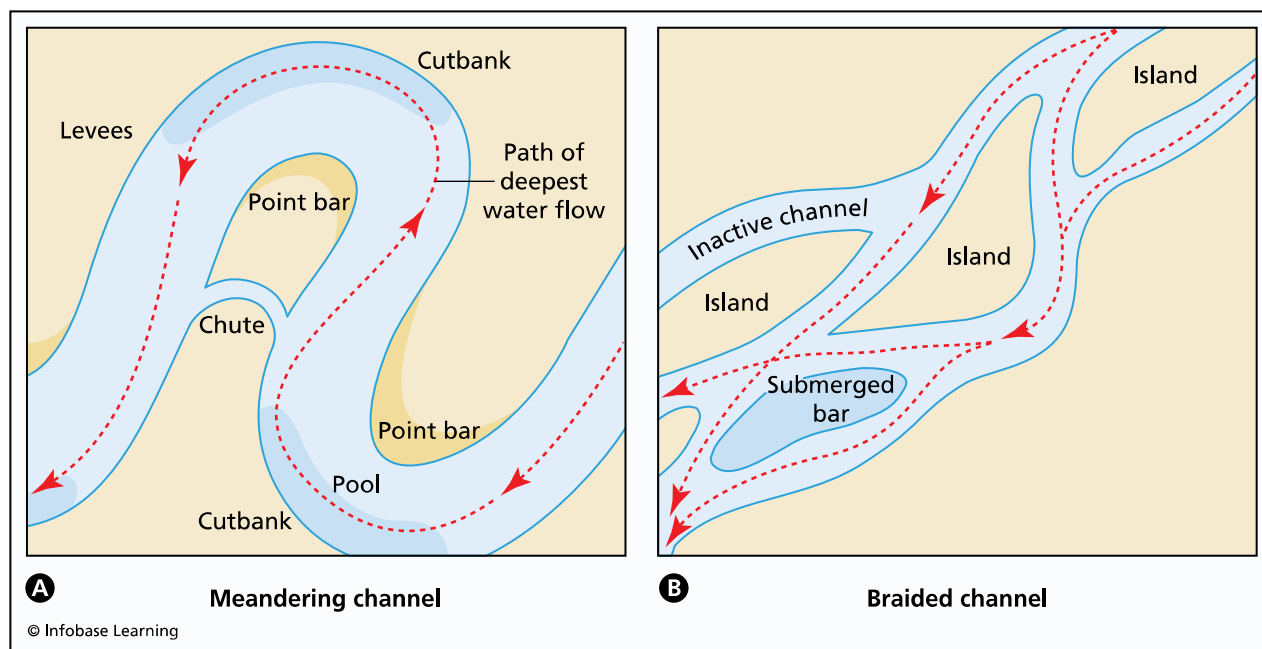
Virtually all streams in the United States are polluted to some degree. Streams in industrial areas are highly affected and can be dead, supporting no aquatic life. Pollution can enter streams in a number of ways. Historically, streams and rivers made a convenient disposal site and pollutants were dumped directly into them. The practice was so brazen that discharge pipes from public sewer systems simply emptied raw sew-

age into rivers downstream of the city or town. The next city down drew their drinking water from the affected river, added their own waste, and, in turn, discharged it on the downstream side of the city, as well. It was estimated that by the time water reached the intakes for the city of New Orleans on the Mississippi River, it had been used six times.

Municipal wastewater discharge and the spills and leaks from industrial sites along a river form the majority of point source pollution into a river. Industrial plants have traditionally been located along rivers because of the ready source of water that might be used in manufacturing and processing and because of the convenience of the river for shipping products. Historically, the companies also discharged their waste directly into the water regardless of the environmental impact. In cases such as Ohio's Cuyahoga River, there were so many flammable chemicals in the water that the river periodically



Block diagram showing the morphology of streams and the possible sources of water that recharge the stream



**Maps of two general types of streams: Meandering streams occur in areas of flat topography, have slower flow velocity, and have sinuous channels with distinctive features (A); braided streams occur in areas of rugged topography, have high flow velocity, and have anastomosing channels with sediment stored in the channel bars (islands) between them (B).**

caught fire. In the Hudson River of New York, so much dioxin was dumped into the river that a 100-mile (160-km) stretch of it is a single Superfund site. Even if the waste was dumped or buried along the shore, flooding and runoff during precipitation and thawing events washed the pollution into the river. In the case of effluent streams, groundwater could also carry dissolved pollutants into the river through base flow. Clearly, industrial sites are capable of inflicting serious damage on the health of a river.

Surprisingly, nonpoint source pollution can be as dangerous as point source pollution. The mechanism for this pollution is the precipitation and subsequent surface runoff within the watershed of a river. The entire area from which water is derived to feed a river is its watershed. Depending upon the river, this can be quite a large area, up to thousands to hundreds of thousands of square miles. Anything that is applied to the surface generally enters the river eventually. In agricultural areas, runoff from fields can contain concentrated amounts of fertilizers and pesticides. In suburban areas, runoff flows from lawns, paved areas, and buildings into storm drains, which discharge directly into streams. The runoff can contain fertilizers, pesticides, road salt, motor oil and antifreeze, paint residues, detergents, solvents, and many other residential pollutants.

With all these dangerous pollutants in our rivers and streams, it might be surprising that the overabundance of fertilizer could actually be the greatest

threat. The active ingredients in fertilizers are nitrates and phosphates. They nourish plants and make them grow faster, larger, and stronger. In water, they nourish algae and other aquatic plants, which flourish even more than the land plants. When they die, microorganisms consume them and oxygen in the process. Hypoxic conditions result in the water, which can kill fish and other animals that depend on oxygen in the water. This process is called eutrophication, and nearly every body of water on land suffers from it. The more recent development is that the oceans suffer from fertilizers in rivers also. When the river empties into the ocean, it delivers water laden with fertilizers. Scientists used to believe that oceans were so large that they simply absorbed the nutrients. This belief was disproven when, in the 1960s, a large zone of eutrophication was found in the Black Sea in the USSR. Since then, such large dead zones have been appearing at the mouth of most major rivers worldwide. Today, there are some 200 dead zones, including one at the mouth of the Mississippi River in the Gulf of Mexico that is as large as the state of New Jersey. These dead zones make large areas of ocean completely unproductive and reduce the ability to produce sufficient food for the burgeoning human population.

See also CUYAHOGA RIVER POLLUTION; DEAD ZONE; INFLUENT/EFFLUENT STREAMS; EUTROPHICATION; HUDSON RIVER PCB POLLUTION; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; WATER POLLUTION.

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### Stringfellow acid pits Glen Avon, California (1975–present) *Water Pollution*

From about the turn of the 20th century, the owners and operators of the Stringfellow Quarry Company blasted and removed granite from a 22-acre (8.9-ha) pit in the Jurupa Mountains, near the southern end of the Sierra Nevada in California. In 1956, they obtained a favorable land use variance from the Riverside County Planning Commission to operate one of California's few fully licensed class I Hazardous Waste Disposal facilities. They had made a fortune taking rock out of the ground; now, they would make an almost equal sum of money filling this hole in the earth with more than 34 million gallons (128.7 million L) of industrial waste, generated by metal finishing and electroplating plants from nearby Los Angeles, but also agricultural chemicals (primarily dichlorodiphenyltrichloroethane [DDT]) and organic solvents for the next 17 years, until 1973. Geologists of the state of California agreed with the description provided by the Stringfellow Quarry Company in its permit application that the granite taken from the mountain range left behind a natural impermeable bowl, one that would not leak. It was a perfect place to accept and process hazardous industrial waste, which would effectively isolate the material from the environment. Unfortunately, both the government geologists and the company were wrong.

### POLLUTION OF THE SITE

Just five miles (8 km) northwest of the city of Riverside and only one mile (1.6 km) north of Glen Avon, Stringfellow Quarry lies in a natural canyon on the southern slopes of the Jurupa Mountains. This canyon serves as part of the area's natural drain-

age network for Pyrite Creek, which feeds part of the Chino III groundwater basin. This basin stores and transmits potable groundwater for the 40,000 residents living in the relatively arid area of Southern California. Groundwater from this basin is also used extensively for industrial and agricultural purposes. Excess surface runoff from the canyon flows southwesterly through Glen Avon in a series of lined and unlined channels and ditches. Eventually, this water discharges to the Santa Ana River, approximately seven miles (11.3 km) from the site.

During site operations, disposal techniques included discharging liquid wastes, mainly acids and heavy metals, to ponds that were locally called acid pits and letting the water evaporate, as well as any liquid organic solvents or degreasers, leaving behind a sticky metal sludgelike residue. Once one pond was full, another was opened. Liquids also were sprayed high into the air to accelerate the evaporative process. The primary metals handled by the facility included chromium and cadmium in addition to other chemicals such as sulfuric acid and organic solvents including trichloroethene (TCE).

Site operations proceeded uneventfully until an unusually heavy rainstorm in 1969. Rainwater filled the open acid pits and flushed contaminated sludge and runoff down Pyrite Creek and through the center of Glen Avon. As a result, the community began to lobby for the closing and cleanup of the site. By 1972, under close regulatory scrutiny and with its customers starting to question the environmental integrity of the facility, the owners voluntarily ceased operations. The business unraveled quickly: The site's land use variance was revoked in 1974, and in 1975 the operating corporation notified the local Regional Water Quality Control Board (RWQCB) that it was financially unable to continue maintenance of the site. They had not paid any property taxes since 1973. The owners and operators of the Stringfellow Acid Pit site, as it was to become known, simply walked away.

### THE CLEANUP

In 1975, the RWQCB declared the nonoperating site a public nuisance and placed a lien on a plot of land filled with hazardous and toxic wastes. They later tried to sell this lien to raise money for the study and cleanup of the property. There were no takers. In 1978, the California state legislature appropriated funds for abatement activities at Stringfellow. Before these activities could begin, however, a heavy rainfall in spring 1978 again caused the waste pits on the site to overflow into Pyrite Creek. To prevent a catastrophic release, the RWQCB supervised the

release of approximately 800,000 gallons (3.03 million L) of chemically contaminated water into Pyrite Creek. The residents of Glen Avon were irate when these carcinogenic and toxic materials flowed past their homes and businesses.

Over the next three years, the RWQCB arranged for the removal and off-site disposal of approximately 6.5 million gallons (24.6 million L) of liquid wastes, as well as DDT-contaminated material. By this time, both the state and the RWQCB were beginning to realize that the magnitude of the environmental problems present at the Stringfellow site far exceeded their available resources. Fortunately, the national media had begun to focus the country's attention on sites such as Stringfellow, Valley of the Drums, Kentucky, and Love Canal, New York, and, on December 11, 1980, the U.S. Congress passed and President Jimmy Carter signed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) into law. One of the most important parts of this groundbreaking legislation was the development of the National Priorities List, or NPL. This list served as a compendium of the United States' worst abandoned or inactive hazardous waste disposal sites, those that represented an imminent danger to public health or the environment. To provide money to clean up these sites, a tax was imposed on the petroleum and chemical industries, with those revenues going to a Superfund, a large pool of dollars created to fund the cleanup of those types of facilities.

The Stringfellow property was acquired jointly by the state of California and Riverside County via a tax deed, and, in 1981, California assumed sole title to expedite the cleanup. Although RWQCB pressed for complete removal of all wastes from the property, it became clear that the process would be prohibitively expensive. The state authorized funding to implement interim remedial measures of capping and pit stabilization to prevent further uncontrolled discharges from the facility and to study local groundwater to assess the extent of potential impacts from the site. Designated by the then-governor Jerry Brown as the most contaminated site in California, Stringfellow was added to the NPL in September 1983.

Another key component of CERCLA was the establishment of joint and several liability for those who caused or contributed to the contamination. Any business, company, or person whose activities resulted in the illegal disposal or release of hazardous substances or materials was responsible for the cleanup of the entire contamination, not just part of it. Using this new legislative authority, the EPA contacted the responsible parties (RPs), those com-

panies that were identified as having sent waste to the Stringfellow Acid Pit site for disposal. These companies became responsible for the \$150 million in remediation costs and subsequently reimbursed the EPA and state of California for most of the prior site stabilization and groundwater cleanup activities.

Over the years following the site's voluntary 1972 closure, a plume of contaminated groundwater had formed and extended more than one mile (1.6 km) from the Stringfellow site through Glen Avon. To address the groundwater contamination, the EPA constructed a slurry wall to block further contaminated groundwater migration and a French drain to capture contaminated surface water downgradient of the acid pits. In addition, a series of interceptor recovery wells were installed to remove contaminated groundwater and hydraulically to contain it from clean groundwater. These wells pumped the groundwater to a wastewater treatment plant. Once at the plant, the metals in the groundwater, including chromium, cadmium, copper, and zinc, were precipitated out by using lime. The water was then passed through a bed of granular activated carbon to remove the organic solvents (primarily TCE), and it was eventually discharged to the municipal sewer system for final treatment before release to the surface water.

Sludge from treatment operations was trucked 200 miles (320 km) to another California class I hazardous waste disposal facility. The treatment plant cost about \$10 million to build and about \$1.5 million per year to operate. It has been recovering and treating 200,000 gallons (757,000 L) of contaminated groundwater per week. It is still in operation.

### A FINAL PROBLEM

At the time, the Stringfellow site was one of the most notorious Superfund sites in the United States and, like any government program, was only as good as the people managing it. In this case, it was Rita M. Lavelle, a longtime California state Republican political figure. She was appointed as assistant administrator to USEPA in 1982 by President Ronald Reagan, also from California. Ms. Lavelle had worked developing environmental compliance policies for several major California-based corporations, and considering her political acumen and environmental advocacy, she seemed to be the perfect candidate for the job. Working closely with the EPA's national administrator, Anne Gorsuch (later Burford), Ms. Lavelle assumed responsibility for disbursement of Superfund monies. She and her staff determined the amount of money a particular site or community received for remedial activities.



The first signs of trouble appeared about 10 months after Lavelle's appointment. Her staff began grumbling that she was proindustry and that she was too willing to settle disputes quietly and allow companies to avoid more costly and reputation-damaging fines. In September 1983, a congressional subcommittee, which had been investigating EPA's handling of Superfund for several months, requested documents describing cleanup activities at 160 Superfund sites across the country. At about the same time, another subcommittee, acting on a complaint from EPA staffers and a community group near the Stringfellow site, began an investigation to determine whether Ms. Lavelle was preventing the release of a \$6.1 million remedial grant for Stringfellow until after the November election. The contention was that Ms. Lavelle did not want California's Democratic governor, Jerry Brown, to be able to claim credit for the cleanup of Stringfellow during his Senate campaign.

Both congressional subcommittees issued subpoenas for EPA documents, but Administrator Burford, acting at the direction of the White House, claimed executive privilege and refused to turn over any materials. Executive privilege commonly is defined as the right of the president and high-level executive branch officers to withhold information from those who have compulsory power, including Congress and the courts (and therefore, ultimately, the public), when there is a need to protect national security, the confidentiality of White House policy discussions, or legal deliberations. In testimony before one of the investigating House subcommittees, Ms. Lavelle denied that any such funding manipulation had taken place. She also denied that she ordered the EPA inspector general to harass an EPA staff member who had publicly criticized the agency on the popular news program *60 Minutes* for these and other types of politically based actions.

As Administrator Burford reviewed the EPA's internal documents, however, she realized Ms. Lavelle had attempted to manipulate Superfund disbursements for political reasons and had committed perjury. She met with Lavelle and requested that she resign. Lavelle refused, and President Reagan tersely fired her shortly thereafter. Ms. Lavelle was later convicted of lying to Congress and served three months of a six-month prison sentence. In 2004, Ms. Lavelle was found guilty once again for wire fraud and making false statements to the Federal Bureau of Investigation (FBI) in connection with a fraudulent billing scheme related to the disposal of hazardous wastes. She was sentenced to 15 months in federal prison.

Another Stringfellow casualty was Anne Burford, the former head of the EPA under President Reagan. After claiming executive privilege for the Stringfellow-related documents, as she was directed to do by the White House, Burford was indicted for contempt of Congress. As it became clear that the information in the documents was not related to policy development or national security, but rather demonstrated significant malfeasance by Ms. Lavelle, Burford urged President Reagan to release the documents. The information in the documents created political turmoil in the press and Congress, and there were several calls for Burford's resignation. Shortly after the release of the subpoenaed documents, the Justice Department advised Burford that they could not defend her in the contempt of Congress charge, and, facing a long and expensive legal battle, Anne Burford was forced to resign, along with 20 other senior EPA staff. In response, Congress rescinded the contempt citation. Ms. Burford died of cancer in 2004.

See also CADMIUM; CHROMIUM; DDT; ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; LOVE CANAL; SUPERFUND SITES; TCE; VALLEY OF THE DRUMS; WELLS; ZINC.

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**Stumm, Werner (1924–1999)** *Swiss Aquatic Chemistry and Pollution* Dr. Werner Stumm is probably the single most important person responsible for the quality of water that is enjoyed in developed countries. Basically, he addressed and answered all of the first-order issues of water science, and all other researchers have been simply filling in the few holes that he did not address. His method was to explore the molecular aspects of the environmental chemistry of solid-fluid interfaces. This process revolutionized water science, and he literally wrote the book on aquatic chemistry with it. Although his

research was on the technical aspects of environmental issues, in terms of the understanding of chemical processes and interactions, it always had applied results, and he participated actively in the transfer of the theoretical to the applied processes. As a result, wastewater treatment plants run more efficiently and release less pollution and drinking water is cleaner. Coastal communities and those around closed bodies of water also now enjoy a better quality of life with reduced pollution as the result of Dr. Stumm's efforts.

In his first and main issue, Dr. Stumm contributed significantly to understanding and addressing of eutrophication, the overfertilization that ultimately clogs lakes, rivers, and reservoirs with excessive vegetation and reduces oxygen content of the water. He showed that the main problem results from the concentration of phosphorus due to agricultural and urban wastes. The direct result of his research was that the use of phosphorus in agricultural areas was reduced and even in everyday consumer items such as laundry detergent, which used to contain much phosphorus prior to Stumm's work. His research results also resulted in the technology to remove phosphorus from wastewater and drinking water.

Dr. Stumm also studied the corrosion of materials and transmission of metal ions into the environment. This work primarily concentrated on iron and manganese cycling in aquatic systems. This cycling is very complex, with ions, reactive particles, and algae and aquatic organisms all playing a role. The results of this research have been applied to many common problems such as acid precipitation, acid mine drainage, the transport of particle reactive pollutants into lakes and reservoirs, and the removal of iron and manganese from drinking water. As a result, our drinking water is cleaner, there are new regulations on acid contents of air and water, and lakes and reservoirs are cleaner.

Werner Stumm introduced a new holistic approach to water chemistry and, with his protégé, James Morgan, wrote the seminal textbook *Aquatic Chemistry*, which has sold more than 40,000 copies. In this book and in his 15 others and more than 300 professional articles, Stumm developed environmental chemistry to the level of the most advanced chemical research. The work and dissemination thereof advanced other scientific disciplines that overlap water chemistry, such as limnology, oceanography, ecology, soil science, and environmental engineering, and Stumm participated in much of the transference and even the basic research. As an example of how far-reaching his work is, he has one professional article that has been cited more than 1,000 times in other articles. As a result of his steadfast concern

that his results benefit others, all these disciplines are much more effective, and our environment in all of these areas is greatly improved.

After alleviating many of the main water pollution issues through detailed research, Dr. Stumm would seem to have every reason for optimism that humans could overcome all environmental problems given time and interest. This, however, was not the case. Instead, he issued stern warnings that measures to isolate and protect the environment such as air cleaning and wastewater treatment plants will not significantly slow its destruction. The ever-increasing population density, coupled with the high economic and technological demands of lifestyles in industrial nations, will continue to cause significant pollution and continue to impair the Earth's environment. Dr. Stumm warned that population growth must be halted during the course of the next two generations, and the consumption of goods and resources must be controlled. Otherwise, Stumm warned, "the heightened expenditure of energy will progressively disturb (the Earth's) hydrogeological cycles and call into question the preservation of our life support systems."

### BIOGRAPHICAL INFORMATION

Werner Stumm was born on October 8, 1924, in Wolfhalden, Switzerland, where he spent his childhood. He attended the University of Zurich, where he was awarded his Ph.D. in 1952 with a dissertation on inorganic chemistry. He then obtained a position on the staff of the chemistry division at the Institute for Water Resources and Water Pollution Control at the Swiss Federal Institute of Technology in Zurich, where he first encountered problems of water pollution. Stumm applied for and was awarded a postdoctoral fellowship at Harvard University in 1954 in the Department of Engineering and Applied Physics. He performed so well as a postdoctoral fellow that he was asked to join the faculty at Harvard University in 1956 as an assistant professor of sanitary chemistry. By 1961, Stumm was awarded the prestigious position of Gordon McKay Associate Professor of Applied Chemistry and in only three more years the Gordon McKay Professor of Applied Chemistry. It is rare that any associate professor can be promoted to full professor in three years; at Harvard University it is nearly nonexistent. In 1968, Werner Stumm finally became a U.S. citizen.

No sooner had Stumm changed citizenship than he was offered a prestigious position back in his home country of Switzerland. Even more enticing was that it was a professorship and the director position at the Institute for Water Resources and

Water Pollution Control at the Swiss Federal Institute of Technology in Zurich, where he had begun his career 18 years earlier. He accepted the position in 1970 and remained there for the rest of his career, until 1992. During that time, he built up the Institute for Water Resources and Water Pollution Control with some of the best environmental scientists in the world through his reputation and abilities. He posed the research questions that became the major efforts and accomplishments. As a result, it went from being a decent research institute to, without argument, the preeminent environmental research lab in the world. He was so generous with his time and energy with his students and colleagues that he was referred to as “father doctor” by the many people he mentored.

Werner Stumm retired in 1992 and moved to Kusnacht, Switzerland, but remained active in scholarship. He died at his home on April 14, 1999.

### RECOGNITION AND AWARDS

The research accomplishments of Werner Stumm were well recognized by the research community of the world with the awarding of numerous prestigious honors and prizes. He received the Monsanto Prize for Pollution Control in 1977 from the American Chemical Society, the Albert Einstein World Award of Science in 1985 from the World Cultural Council, the Tyler Prize for Environmental Achievement in 1986, the Simon W. Freese Award in 1991 from the American Society of Civil Engineers, the Goldschmidt Medal in 1998 from the Geochemical Society, and posthumously the Stockholm Water Prize in 1999, among many others. He was awarded numerous honorary doctoral degrees from such institutions as the University of Geneva, KTH Stockholm, University of Crete, Northwestern University, and Technion. Stumm was also elected to the U.S. National Academy of Engineering in 1991.

See also EUTROPHICATION; PHOSPHORUS; WATER POLLUTION.

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**styrene** Some substances are used virtually every day by most people and are never thought of as potential environmental or health hazards though

they may be. This is the case with styrene, which is most commonly used to make polystyrene. Polystyrene is in foam drinking cups and food packaging, as well as a number of very common items. It is also used in numerous other common applications including all latex items. Styrene is also known as vinyl benzene, Phenethylene, Cinnamene, Diarex HF 77, Styrolene, Styrol, and Styropol. Styrene has been ranked as the 271st worst environmental threat of the 275 chemicals on the 2007 CERCLA Priority List of Hazardous Substances, and it has been found in 52 of the first 1,177 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where it was tested. It is the properties of styrene and its metabolite, styrene oxide, that make it a health and environmental threat and why its use and release must be regulated.

### PROPERTIES, USE, AND PRODUCTION

Styrene is both naturally occurring in plants and foods including vegetables, fruits, nuts, and meats and synthesized in a laboratory. Synthetic styrene is a colorless to yellowish oily organic liquid with a strong floral odor. It is an aromatic hydrocarbon that is volatile and flammable. Styrene oxide is a colorless to straw-colored liquid with a sweet, pleasant smell. Styrene is primarily used in the manufacture of plastics, synthetic rubber, resins, and insulators through the chemical production of polystyrene (PS), acrylonitrile-butadiene-styrene (ABS), styrene-acrylonitrile (SAN), styrene-butadiene rubber (SBR), styrene butadiene latexes (SBL), and unsaturated polyester resin (UPR) (fiberglass resin). The most common products of these compounds are food and industrial packaging, insulation (electrical and thermal), adhesives, concrete products, fiberglass, pipes, automobile parts, drinking cups and other “food-use” items, and carpet backing. Other styrene products include protective surface coatings, paints, construction materials, and boat manufacture materials, and a flavoring agent for ice cream and candy. Styrene oxide is used in the manufacture of resins, surface coatings, and agricultural and biological chemicals, as well as perfume (oil of roses) and cosmetics. Smaller-scale applications include hydraulic fluids, chlorinated cleaning products, petroleum distillates, dielectric fluids, and the treatment of fibers and textiles.

The production of styrene greatly increased in the 1940s as a result of the wartime demand for synthetic rubber. By 1988, production in the United States had reached 8.5 billion pounds (3.9 billion kg), and it increased to 10.1 billion pounds (4.6 billion kg) by 1993. That year, exports were 1.6 billion

pounds (0.73 billion kg) and imports were 552 million pounds (250.9 million kg). The distribution of this consumption was 66 percent for polystyrene, 11 percent for ABS and SAN resins, 6 percent for SBR (synthetic rubber), 6 percent for SBL (latex), 5 percent for UPR fiberglass resin, and 6 percent for miscellaneous copolymers. There is not much information on the production of styrene oxide, but, in 1990, it exceeded one million pounds (454,000 kg) for the year.

### ENVIRONMENTAL RELEASE AND FATE

In addition to being released as a point source pollutant from manufacturing and storage facilities or from improper disposal, there are several nonpoint sources of styrene including tobacco smoke, automobile exhaust, oxyacetylene welding, burning of brake linings, and waste incineration, among others. Most environmental release of styrene is to air or on land. In air, styrene is mainly in vapor form and reacts quickly with ozone and hydroxyl radicals produced by photochemical reactions. The removal half-life rate is nine hours from reaction with ozone and 3.5 hours from reaction with hydroxyl radicals for a combined 2.5-hour rate, depending upon physical and chemical conditions. If styrene attaches itself to dust particles, it may persist longer and be transported great distances. If released into water, styrene evaporates quickly from the surface at a removal half-life rate of 0.6 day from streams and rivers, depending upon flow rate, and 13 days from ponds and lakes. If released to soil, styrene evaporates quickly from the surface, but, once below the surface, it is much more persistent. Removal from soil is primarily through biodegradation because it has a low mobility in soil. In one study, after 16 weeks, 95 percent of styrene had been removed from landfill soil and 87 percent had been removed from a sandy loam through microbial action. Styrene has been found in drinking water in a few instances, including the water supply of Cincinnati, Ohio, but such an occurrence is rare.

The EPA Toxic Chemical Release Inventory of 1987–93 records industrial release of more than 2 million pounds (909,090 kg) of styrene to the terrestrial environment. More than 85 percent of the release was to land (15 percent to water), and it was primarily from manufacturers of adhesive, sealant, concrete, synthetic rubber, and plastic parts and resins. The states with the highest environmental release of styrene are, in rank order, Texas, West Virginia, Indiana, Wisconsin, Ohio, Georgia, Louisiana, Florida, New York, and Kentucky. Releases into the air, however, were 34.2 million pounds

(15.5 million kg) in 1992 alone. Industrial release of styrene oxide to the environment has been less than 100 pounds (45 kg) per year since 1994.

### HEALTH EFFECTS FROM EXPOSURE

Exposure to styrene and its metabolite, styrene oxide, has been shown to produce a variety of adverse health effects primarily in animals but also in workers in styrene-based industry. Acute exposure to styrene mainly affects the central nervous system causing depression, concentration problems, muscle weakness, tiredness, and nausea. It may also result in irritation of the eyes, nose, and throat. Chronic (long-term) exposure to styrene may also damage the central nervous system (CNS) with symptoms such as headache, fatigue, weakness, depression, CNS dysfunction, hearing loss, and peripheral neuropathy, as well as damage to the liver, kidney, blood, and immune system. Increased maternal and fetal mortality rates, as well as decreased birth weights, were found when pregnant animals were exposed to styrene.

The EPA has classified styrene as a group C possible human carcinogen, and the International Agency for Research on Cancer has classified it as a group 2B, possible human carcinogen, but the styrene oxide metabolite as a group 2A, probable human carcinogen. Most of the evidence for its classification as a carcinogen is from animal tests, although one study found a link to human leukemia and lymphoma. In laboratory animals, an increased incidence of cancer of the lungs, bronchial tubes, liver, lymph glands, mammary glands, and blood (leukemia) was found as the result of exposure to styrene in a variety of animals. Styrene oxide produced tumors in the forestomach and liver of laboratory animals. It was also found to be a genotoxin, causing chromosome damage, deoxyribonucleic acid (DNA) strand breaks, DNA adducts, and mutations in numerous cell types in laboratory tests.

### REGULATIONS ON HUMAN EXPOSURE

As a result of these adverse health effects and the threat to public health, federal regulatory agencies have established limits on styrene exposure. The EPA limits styrene in drinking water to 0.1 part per million (ppm) under the Safe Drinking Water Act. They further require the reporting of the release of 100 pounds (45 kg) or more of styrene oxide. The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) for styrene of 50 ppm and a short-term exposure limit (STEL) of 100 ppm over an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health



(NIOSH) set a similar exposure limit (REL) of 50 ppm over an eight-hour day with a short-term exposure limit of 100 ppm. The immediately dangerous to life and health designation is for levels of 700 ppm or more. The NIOSH 1982–83 National Occupational Exposure Survey estimated that 108,000 workers were exposed to styrene. A recent EPA survey places the current number at about 90,000 workers.

See also ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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### Sudbury mining and air pollution Sudbury, Ontario, Canada (1986–present)

**Soil Pollution** Nowhere has the connection between air pollution and ecological collapse been better demonstrated than in one of Canada's largest metropolitan areas, Sudbury, Ontario (population 120,000), located about 200 miles (322 km) north of Toronto. Sudbury includes an area of more than 1,000 square miles (2,590 km<sup>2</sup>) and is really an amalgamation of seven former separate small municipalities. The seeds of Sudbury's environmental devastation began long before the Industrial Revolution.

#### BACKGROUND

About 1.9 billion years ago, a meteorite struck the Earth 200 miles (322 km) north of Toronto. Out of this cataclysmic event, a bowl-shaped basin formed

that was some 40 miles (64.4 km) long, 20 miles (37.2 km) wide, and 10 miles (16.1 km) deep. The heat and pressure of the impact melted rocks, and minerals seeped to the surface through the fractures along the rim of this basin. These minerals formed one of the world's most important reserves of nickel and copper. Today, approximately 60 percent of all underground hard rock mining in Canada takes place within a radius of 300 miles (482.8 km) of Sudbury. There is more than 3,200 miles (5,150 km) of tunnel or drifts under the area.

The first environmental destruction of the area, however, was not caused by mining but by logging. The area around Sudbury began to be commercially logged in the early 1870s. Using the existing well-developed river system, pine and cedar were floated to Georgian Bay and Lake Huron for export to the United States. The timber from these logs was used in the rebuilding of Chicago after the Great Fire in 1871.

When permanent settlers began arriving in Sudbury a few years after logging began, large areas of forest were quickly clear-cut to make way for towns, railroads, and farms. Clear-cutting, however, left extensive amounts of scrub, leaves, branches, and small trees unsuitable for timber. Once this "slash" material dried, it created an ideal environment for wildfires, and over the next 20 years, countless conflagrations swept across the Sudbury landscape. Ironically, the timber used to rebuild after a fire in the United States created a legacy of fire for the community in Canada that supplied it.

Finally, in 1885, a surveyor for a railroad company discovered the richest deposits of nickel in the world within the meteorite impact zone. Shortly thereafter, significant deposits of copper also were found. Mining began almost immediately and continues today, more than 120 years later. The extraction and processing of these minerals, however, had environmental cost. The copper and nickel are bound up in the minerals pentlandite [(FeNi)<sub>9</sub>S<sub>8</sub>] and pyrrhotite [Fe<sub>1-x</sub>S], which are also rich in sulfur. The presence of this sulfur is a nuisance: It interferes with mineral refining and detracts from the high melting points, malleability, and electrical conductivity that make these metals valuable.

#### POLLUTION OF THE SITE

To remove the unwanted sulfur, ores were roasted in open burn pits. A mixture of ore and wood was kept burning for months in order to ready the ore for loading into a furnace for further processing. The heat and air of the roasting converted sulfur to sulfur dioxide (SO<sub>2</sub>), a major cause of acid rain. Roasting was typically used to remove sulfur until



**Ecosystem devastation near INCO nickel mine and smelter, Sudbury, Ontario, Canada, 1994** (© Paul A. Soders/CORBIS)

environmental regulations prohibiting the uncontrolled discharge of  $\text{SO}_2$  directly to the atmosphere were established.

Open air roasting in Sudbury was gradually replaced by ore processing at higher temperatures in enclosed vats or tanks inside buildings.  $\text{SO}_2$  was still emitted, but stacks distributed it across a wider area, thus diluting its effects. In 1965, a record 2.5 million tons (2.3 million metric tons) of sulfur dioxide was discharged into the atmosphere around Sudbury. In addition, as mining continued, tailings and slag began to accumulate to such a degree that by 1984, the cumulative area occupied by these waste products was more than 3,000 acres (about five square miles [ $13 \text{ km}^2$ ]) with new material added at the rate of about 8 million tons (7.3 million metric tons) per year. Modern smelting plants use gas-scrubbing systems to remove  $\text{SO}_x$  to produce sulfuric acid as a commercial by-product.

The combination of clear-cut logging, fires, mining, and ore roasting/smelting proved too much for the Sudbury ecology. The soil system disintegrated, either washing away through the lack of vegetation or becoming sterile through acidification by  $\text{SO}_2$  emissions. Soil near most roasters and smelters

became toxic as a result of the elevated levels of copper and nickel discharged into the air, which subsequently settled onto the ground. Over a larger area, aluminum, leached by acid rain from minerals in the soil and bedrock, began to concentrate in the soil and started to interfere with plant growth and reproduction.

The phytotoxic effects were widespread. By 1967, most vegetation within 40 square miles ( $103.6 \text{ km}^2$ ) of Sudbury was dead. Within 140 square miles ( $362.6 \text{ km}^2$ ), only shrubs and secondary herbaceous cover were able to grow, and signs of distressed vegetation were visible within a 1,700-square-mile ( $4,403 \text{ km}^2$ ) area. The remaining soil had an acidic pH of 2.0–4.5 and was deficient in phosphorus and nitrogen, as well as calcium, magnesium, and manganese, all of which are essential plant nutrients. Soil close to the smelters had concentrations of copper and nickel often exceeding thousands of parts per million (ppm), hundreds of times higher than regulatory limits. The landscape became a bleak, barren surface of black rock so unique that during the 1970s, National Aeronautics and Space Administration (NASA) astronauts prepared for Moon landings by training around Sudbury.

### THE CLEANUP

Local residents recognized their dependence on nickel and copper and were hesitant to protest to the companies that provided their livelihood. Gradually, however, attitudes began to change. Several half-hearted attempts at restoration had been attempted over the years. In 1947, residents of the nearby town of Copper Cliffs tried to reduce dust by planting a variety of grasses and legumes on a mine tailings pile. During the 1950s, tree stumps were removed in some areas and new trees planted in imported soil to reestablish local vegetation.

In 1969, a joint program of the Ontario Department of Lands and Forests and the Laurentia University Biology Department, known as the Sudbury Environmental Enhancement Programme (SEEP), was initiated to study ways to restore the area. Initially focused on improving soil fertility, SEEP also implemented a number of restoration projects. SEEP organized the removal of dead trees and branches from barren and semibarren areas, limed and fertilized soil, and began reforestation by planting thousands of trees.

By 1986, about 10 square miles (25.9 km<sup>2</sup>) of land was involved in some stage of reclamation. Although the goal of this effort was primarily aesthetic, with restoration concentrating on creating “green belts” along highways, neighborhoods, and in a few public parks, by 1995, the results were noticeable. More than 230,000 trees had been planted, and the number of insects, birds, and some mammals had increased measurably. Although these efforts continue today, it is still far too early to claim success. Only 30 percent of the impacted areas have been addressed, and the local ecology may take hundreds of years to regain a self-sustaining condition.

See also AIR POLLUTION; NICKEL; SULFUR DIOXIDE; SULFUR OXIDE CONTROL TECHNOLOGIES.

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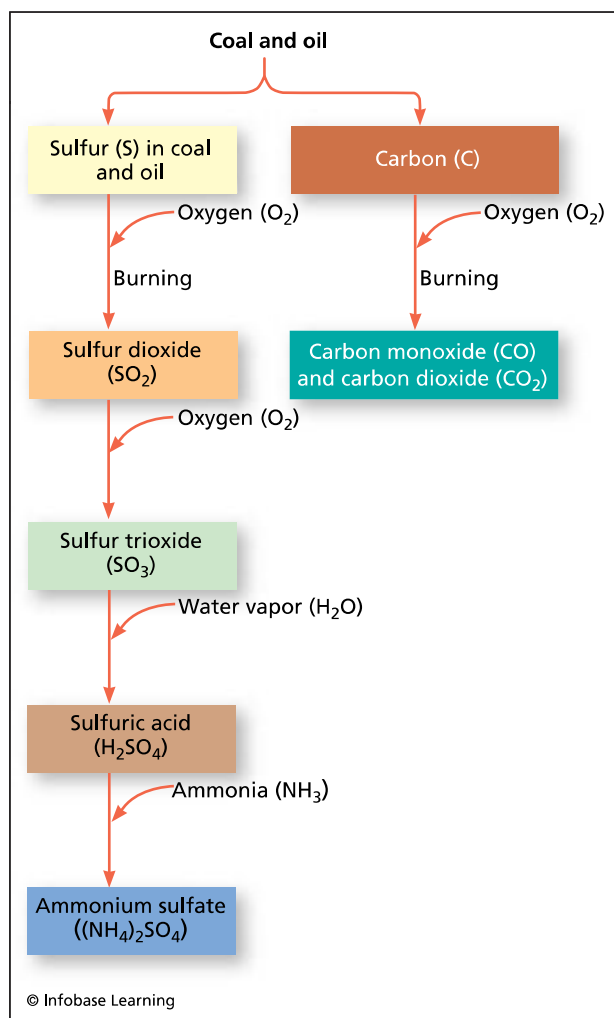
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**sulfur dioxide (SO<sub>2</sub>)** When the federal government first took an interest in ensuring clean air for the citizens of the United States in 1970, six principal air pollutants were identified and efforts were made to reduce their levels. Sulfur dioxide is one of the six, and these efforts have been very successful as the levels have decreased every year since they began. The reason that SO<sub>2</sub> was of such concern is that it is the primary cause of acid rain, which is both a public health and an environmental hazard. The acidity had reached such high levels in some urban and industrial areas, most notably several cities in Japan, that being caught in the rain could result in the need for medical attention. Antiquities, especially those made of marble, in many cities were being quickly destroyed, and modern structures were not safe. Perhaps even more shocking was the discovery that the acid rain could persist long distances from the urban and industrial areas. Emissions from industrial areas in Michigan had caused acid rain to extend all the way to the Adirondack Mountains of New York. As a result, because there is no natural buffering of the acidity, 90 percent of the high-altitude lakes were found to be acidic and dead, devoid of aquatic life. This acidity is the primary reason that SO<sub>2</sub> is considered such a dangerous pollutant.

### PROPERTIES AND PRODUCTION

Sulfur dioxide is a colorless gas with a very strong and acrid odor. It can exist as a liquid under pressure. It is both naturally occurring and anthropogenic. Natural sources are primarily volcanic eruptions, and lesser amounts result from weathering of minerals, including those in coal, and microbial actions on soils and in wetlands. Depending on the year, natural emissions can dwarf anthropogenic emissions and extend into the stratosphere as well as the troposphere. Emission rates from an erupting volcano range from about 44 tons (20 metric tons) to more than 22 million tons (10 million metric tons) per day. The 1991 eruption of Mount Pinatubo injected more than 37.4 million tons (17 million metric tons) into the stratosphere in one day. Human emissions of SO<sub>2</sub> result primarily from burning or refining natural substances. By far and away, the primary sources of SO<sub>2</sub> emissions are fossil-fuel-burning electric-power generating plants, accounting for 67 percent of those produced in the United States; coal-burning plants produce 96 per-





**Flowchart showing the fate of by-products of coal and oil combustion. The sulfur branch produces several air pollutants including sulfuric acid, the primary contributor to acid precipitation.**

cent of those emissions. About 18 percent of the SO<sub>2</sub> is from industrial and residential fuel combustion including automotive emissions and home heating. Some 5 percent is from fuel combustion from all other combustion engines and nonroad vehicles, including ships, trains, and construction equipment, and 3 percent is from metal processing. All other sources produce about 7 percent of emissions.

Sulfur dioxide also has some industrial applications. It has been used as a preservative in some alcoholic drinks, especially wine and beer, and in dried fruit such as apricots because it possesses antimicrobial properties. It has been used as a fumigant for grains, grapes, vegetables, and citrus fruits. It is also used as a bleach for paper, flour, wood pulp, wicker, gelatin, glue, wool, and some textile materials. Prior to the development of chlorofluorocarbons, SO<sub>2</sub> was

used as a refrigerant. It is also used in the manufacture of some chemicals (including sulfuric acid and several fertilizers) and in metal refining, cement production, water treatment, and food processing. These applications are and were relatively minor.

### ENVIRONMENTAL RELEASE AND FATE

Release of SO<sub>2</sub> into the environment causes extensive damage in a number of areas. The most damaging of these effects is acid rain. When released into the air, sulfur dioxide reacts with water and other compounds to form sulfuric acid, sulfurous acid, sulfur trioxide, and sulfates. In addition to the Adirondacks, acid waters as the result of acid rain have been found throughout the Upper Midwest, the central Appalachians, Florida, and many isolated areas in the eastern United States. Acid precipitation as rain, snow, fog, and dry particles has damaged higher-elevation trees from Maine to Georgia, reducing reproduction and making them susceptible to disease and infestation. Even at lower elevations, vegetation, including commercial crops, is adversely affected by the acidity. Runoff from this precipitation strips away nutrients from the soil, further compromising forest and farmland productivity. Once the acid reaches surface water bodies, it lowers the pH to the point where native aquatic species can no longer survive. In Virginia, 6 percent of the streams can no longer support native trout populations, and 50 percent of the remaining streams have severely reduced capacity. In Pennsylvania, the situation is even worse with regard to trout.

Sulfur dioxide also forms particles of sulfates and other compounds in the atmosphere. They scatter incoming sunlight, producing haze and reducing visibility. SO<sub>2</sub> accounts for 50 percent of the reduction of visibility in the eastern United States. These SO<sub>2</sub> aerosols reflect back enough sunlight to cause global cooling. After intense volcanic eruptions such as Tambora and Krakatoa in Indonesia and Mount Pinatubo in the Philippines, the global temperatures decreased significantly as a result of the high-altitude sulfur aerosols.

Some 31.2 million tons (14.2 million metric tons) of sulfur dioxide was released in the United States in 1970. As the result of stringent regulations, it had decreased to 25.9 million tons (11.8 metric tons) by 1980 and 23.6 million tons (10.7 million metric tons) by 1990. In the mid- to late 1990s, the releases ranged from about 18.5 to 19.5 million tons (8.4 and 8.9 million metric tons) with more than 13 million tons (5.9 million metric tons) from power-generating utilities. The reported industrial release for 2005



was 158 million pounds (71.8 million kg). It would appear that SO<sub>2</sub> emissions would have decreased on a worldwide basis, but the 33 percent decrease in emissions from the United States has been offset by a 27 percent increase in SO<sub>2</sub> emissions in China.

Clearly, the vast majority of sulfur dioxide emissions are as nonpoint source pollutants released to the atmosphere. Sulfur dioxide does, however, form a point source pollutant from some industry and waste disposal sites. Sulfur dioxide has been identified in at least 16 of the first 1,467 EPA-designated Superfund sites on the National Priority List.

### HEALTH EFFECTS FROM EXPOSURE

Acute exposure to SO<sub>2</sub> can irritate the nose, throat, eyes, and lungs and cause coughing, shortness of breath, stomach pain, headache, dizziness, nausea, fever, vomiting, serious skin and eye burns, convulsions, pulmonary edema, and death by obstructed air passages and respiratory depression with increasing concentrations. Noticeable symptoms begin at five parts per million (ppm) within 5–15 minutes, burns begin at 20–50 ppm, and death occurs within 10 minutes at 1,000 ppm. Long-term chronic exposure can cause permanent lung damage including emphysema, chronic bronchitis, and other respiratory illness; inhibition of thyroid function; loss of sense of smell; menstrual disorders; decreased fertility in men and women; and premature death. SO<sub>2</sub> is especially dangerous to people who have asthma, heart disease, and lung disease, as well as children and elderly adults. Even low doses may cause life-threatening reactions. Studies have shown a direct correlation between high SO<sub>2</sub> levels in major cities and increases in hospital admissions by as much as 10 percent. Although some studies suggest that SO<sub>2</sub> may cause increased incidence of lung cancer in laboratory animals, the EPA has placed it in group D, not classifiable as a human carcinogen, as has the International Agency for Research on Cancer (group 3).

Sulfur dioxide readily reacts to form sulfates both in natural settings and in the workplace. Sulfates and related compounds can produce acute effects of upper respiratory tract irritation, coughing, choking, difficulty in swallowing, and nosebleeds, leading to constriction of the bronchial tubes and difficulty in breathing within five to 15 minutes. Longer-term exposure may produce chest pain, laryngitis and laryngeal edema, chemical bronchitis and pneumonia, damage to the eyes, pulmonary edema, cyanosis, asphyxiation, and death by respiratory depression and failure.

### REGULATIONS ON HUMAN EXPOSURE

Exposure to sulfur dioxide is regulated by federal authorities to protect public health and that of workers. The U.S. Environmental Protection Agency (EPA) set its long-term (one-year average) air quality standard at 0.03 ppm and the short-term limit (24-hour period) at 0.14 ppm, which should not be exceeded more than once per year. The Occupational Safety and Health Administration (OSHA) set a permissible exposure limit (PEL) for sulfur dioxide of 5 ppm over an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) set an exposure limit (REL) of 2 ppm over a 10-hour day with a short-term exposure limit (STEL) of 5 ppm. The immediately dangerous to life and health (IDLH) designation is for levels of 100 ppm or more. The U.S. Department of Labor estimated that more than 600,000 Americans were occupationally exposed to sulfur dioxide in 1977. The World Health Organization recommends a maximal exposure of 0.175 ppm of SO<sub>2</sub> for periods of 10 minutes or more and 0.04 ppm for periods of 24 hours or more.

In an effort to reduce acid rain, the EPA implemented a program to reduce SO<sub>2</sub> emissions by 10 million tons (4.5 million metric tons) between 1980 and 2010. As part of the program, coal-fired power plants were targeted in two phases; the first began in 1995 and the second in 2000. The first phase addressed plants with the highest emissions and the second addressed smaller plants. Older plants were grandfathered by the EPA during the first part of the project and were consequently used so heavily that sulfur emissions actually increased from 1992 to 1998, but the second phase restricted their use. The most common method of SO<sub>2</sub> reduction uses a device called a scrubber.

See also AIR POLLUTION; MEUSE VALLEY DISASTER; POZA RICA DISASTER; SULFUR OXIDE CONTROL TECHNOLOGIES; SUPERFUND SITES.

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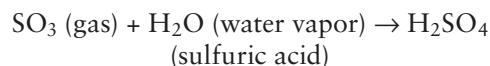
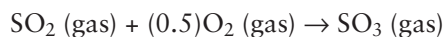
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**sulfur oxide control technologies** Most of the electricity people rely on to maintain the economy and sustain their generally high standard of living is produced through the burning of fossil fuels including coal, oil, and natural gas. The combustion of these fuels, however, exacts a high environmental price in terms of air quality. In addition to NO<sub>x</sub>, the other major air contaminant that is emitted from the incomplete burning of fossil fuel is sulfur oxide, or SO<sub>x</sub>.

Sulfur oxides are a group of colorless gases formed when sulfur is joined with oxygen. This takes place through combustion of fuels containing sulfur, gasoline extraction from oil at refineries, and metal extraction from ore in smelters. The *x* in SO<sub>x</sub> can stand for either 2 or 3, depending upon how the sulfur reacts with gases in the atmosphere once it is released from a stack or vent. Of the sulfur compounds created during combustion, sulfur dioxide (SO<sub>2</sub>) is the most important. It is a colorless gas that can usually be noticed by either smell or taste at concentrations between 0.3 part per million (ppm) and 1 ppm. At concentrations above about 3 ppm, it has a pungent, irritating odor. The main reason to control SO<sub>x</sub> emissions is that both compounds react with oxygen in the atmosphere to form sulfuric acid:



The amount of SO<sub>x</sub> emitted during combustion is related directly to the sulfur content of the fuel. Approximately 95 percent of the sulfur in combusted fuel is discharged as SO<sub>2</sub>. Between 1 and 5 percent combines with oxygen to form SO<sub>3</sub>. Sulfur particulate, which is regulated as particulate matter with a diameter of 10 microns or less (PM<sub>10</sub>), makes up 1–3 percent of the exhaust gas. Sulfur dioxide emissions are regulated by three National Ambient Air Quality Standards (NAAQS) at an annual average of 0.03 ppm (80 mcg/m<sup>3</sup>), a 24-hour level of 0.14 ppm (365 mcg/m<sup>3</sup>), and a 3-hour level of 0.50 ppm (1,300 mcg/m<sup>3</sup>).

This means emissions of gases from smokestacks cannot have average concentrations of sulfur dioxide higher than these values. The first two standards, annual average and 24-hour level, are called public health, or primary, standards. The three-hour level is a secondary aesthetic or quality-of-life-related standard. The annual average standard cannot be exceeded even once, whereas the two shorter-duration values cannot be exceeded more than once per year. Sulfur dioxide is used as the criterion pollutant, the indicator of how much sulfur oxide is present in the air. One of the most dramatic examples of effects of exposure to excessive levels of SO<sub>x</sub> on human health occurred in 1930 in the Meuse Valley, Belgium.

In the United States, the major producers of SO<sub>x</sub> are electric utilities, particularly those that burn coal. About 15 million tons (13.6 million metric tons) of SO<sub>x</sub> is released into the air every year through the generation of electricity by burning coal. Industrial facilities that process raw materials from metallic ores, coal, and crude oil, or that burn coal or oil to produce heat, also contribute to atmospheric SO<sub>x</sub>. These include such economically essential activities as petroleum refining, cement manufacturing, and metal processing. Locomotives, large ships, and some construction equipment burn diesel fuel that has high-sulfur content and release SO<sub>x</sub>.

## CONTROL METHODS

There are several technologies available to control SO<sub>x</sub> emissions. Until the early 1960s, SO<sub>x</sub> emissions were managed primarily through dispersion. A tall stack or chimney was built and SO<sub>x</sub> emissions discharged well above the land surface to prevent the area immediately adjacent to the source from being affected. All this did was to transfer the problem to other areas as the acid rain formed by the SO<sub>x</sub> eventually landed on farmlands, watersheds, and buildings far from where it was released. Air quality standards developed and enforced over the last 30 years are much more stringent and cannot be met by simply transferring the pollution to another area.

Modern SO<sub>x</sub> reduction methods can be broadly grouped into three categories: the use of low-sulfur fuels, removal of sulfur from fuel prior to combustion (fuel desulfurization), and removal of sulfur from the waste gases after fuel combustion (flue gas desulfurization, or FGD).

### Low-Sulfur Fuels

The amount of sulfur in vent or stack emissions is related directly to the sulfur content of the fuel.

Many industries have elected to switch to fuels that contain very low concentrations of sulfur. Regulations by the U.S. Environmental Protection Agency (EPA) require the use of ultralow sulfur diesel fuel (<15 ppm sulfur) for all cars, trucks, buses, and other vehicles since 2006. Many refiners introduced this type of fuel earlier than required, and several states (especially California) developed programs that financially encouraged the early introduction and use of these types of fuels. Burning fuels containing minimal amounts of sulfur significantly lowers SO<sub>x</sub> emissions, eliminating the need to install and maintain expensive air pollution control equipment. Ultralow sulfur fuel, however, is expensive, and its use may require major modifications to plant or facility equipment.

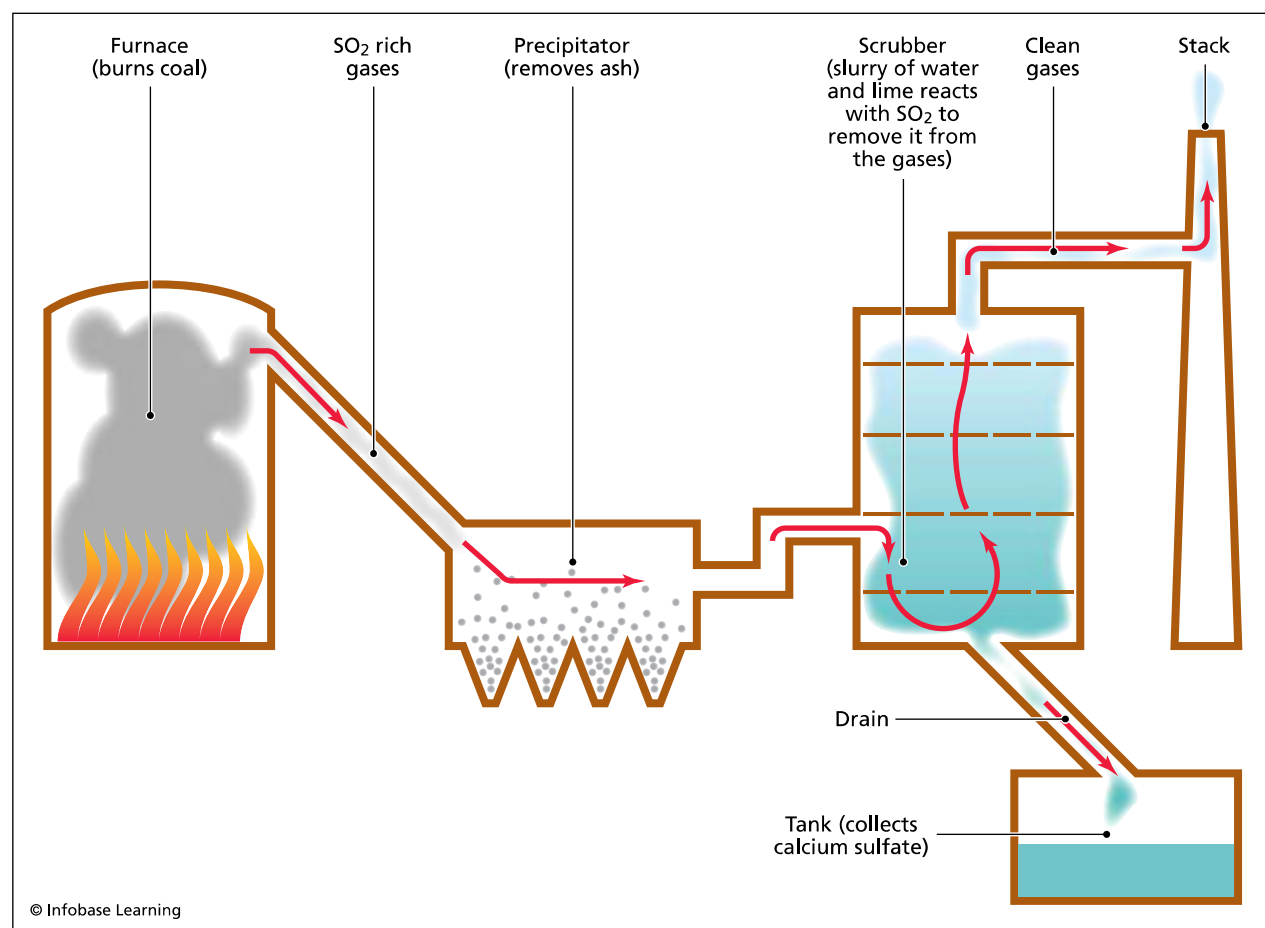
### Fuel Desulfurization

Another way to manage SO<sub>x</sub> emission is to remove the sulfur before the fuel is burned. This process, called desulfurization, is used primarily for coal- and petroleum-based fuels. The sulfur in coal is

present in two forms; it can be chemically bound with the carbon, called organic sulfur, or it can occur as a mineral impurity, called inorganic sulfur. The mineral pyrite (FeS<sub>2</sub>) is the most common form of inorganic sulfur and forms as the organic matter (primarily plant material) is compressed and changed into coal.

Swamps or wetlands that collect organic matter in drier climates commonly contain bacteria that accumulate sulfur and iron. These elements combined to form pyrite as the organic matter was converted into coal. Organic sulfur can only be separated from coal during or after combustion, but inorganic sulfur can be removed during “coal cleaning.”

After mining, almost all coal is processed or cleaned to remove ash-forming minerals and moisture, because they increase transportation costs and reduce burning efficiency at power plants. Ash-forming minerals are impurities consisting of silica, iron, aluminum, and other incombustible matter contained in coal. Coal cleaning, the removal of ash-forming materials, has the added benefit of removing



**Diagram of a sulfur oxide removal system, or “scrubber” for exhaust gases emitted by tall smokestacks. The primary removal mechanism is the reaction of sulfur oxides with lime to produce calcium sulfate.**

## SOME COMMON FUELS AND THEIR AVERAGE SULFUR CONTENT

Fuel	Sulfur Content (weight percent)	Sulfur Content (ppm)
Natural gas	0–0.0007	0–7
Kerosene	0.04–0.3	400–3,000
Gasoline	0.02–0.06	200–600
Diesel fuel (No. 1)	<0.1–0.6	<1,000–6,000
Diesel fuel (No. 2) heating oil	0.6–6	1,000–6,000
Diesel fuel (No. 6)	1–4	10,000–40,000
Coal—western	0.06–0.4	600–4,000
Coal—eastern	3–5	30,000–50,000

pyrite and, therefore, reducing the formation of SO<sub>x</sub> in stack emissions.

Coal cleaning begins with the crushing, grinding, and screening of the material into coarse, intermediate, and fine fractions. The crushing frees ash-forming minerals and pyrite, and grinding results in better physical separation of these materials from the coal. Separation is carried out by hydrocyclone, dense-media, or froth flotation techniques.

Hydrocyclones separate coal from impurities by centrifugal force. The technique is based on the relative density differences between the heavier ash-forming materials and pyrite and the lighter coal. The pulverized coal is mixed with water to form slurry that is fed into a cylinder that has an airstream blowing up through its center. As the slurry circulates, the heavier impurities settle to the bottom, forming a refuse bed, while the air dries and transfers the lighter coal, forcing it into a storage bin.

Dense-media separation technologies also rely on density differences. Instead of using water and air as the separation medium, the pulverized coal is mixed with a fine, heavy mineral. This results in slurry with an average density between those of the heavier impurities and the lighter coal particles. The slurry is fed into a settling tank where the coal rises to the surface and is separated while impurities sink to the bottom. In many applications, a cyclone is used to supply centrifugal force to speed material separation. The separation medium is captured by a strong magnet and recycled. A wide range of coal sizes can be processed by varying the density of the separation medium.

Froth flotation is a coal cleaning process that utilizes the difference in surface characteristics between coal and the ash-forming minerals and pyrite. The coal is pulverized and mixed with water, but, in this case, soap is also added. Air is bubbled through the mixture, and the difference in the density between

the air bubbles and water provides buoyancy that lifts the coal to the surface in a froth that is then skimmed. This procedure is costly and complicated, requiring a high degree of maintenance during operation, and is used principally for metallurgical coal, a grade of coal used for making coke. Coke is produced by partially burning coal in a low-oxygen atmosphere. This leaves a solid that burns at a higher temperature than regular coal. There are two types of coke. Chemical grade coke is used in the production of calcium carbide. Metallurgical grade coke produces a much higher temperature and is used as the heat source in blast furnaces for making steel.

Removal of sulfur from petroleum fuels such as kerosene, gasoline, and diesel is more complicated and takes place as part of the refining process using hydrodesulfurization, also called hydrotreating. Hydrodesulfurization (HDS) is done at temperatures greater than 700°F (371°C), and at pressures exceeding 150 pounds per square inch (10.1 bars). HDS was first used during World War II to meet the demand for very low-sulfur aviation fuels. Today, EPA regulations and those in the European Union require a 90-percent reduction of sulfur content in automotive fuels over previous levels.

HDS entails passing the crude petroleum through a catalytic treatment bed in the presence of hydrogen. This converts the sulfur compounds to hydrogen sulfide. The hydrogen sulfide is then chemically separated, converted to elemental sulfur, and removed. HDS was initially considered the sulfur reduction technology of choice because of the ready availability of reformat, a hydrogen-rich gas produced during petroleum refining using alcohol or hydrocarbon. Hydrogen is expensive to make by itself, and because of this, most refineries recycle the reformat generated by their other activities into HDS processes.



## OTHER TYPES OF WET SCRUBBER SYSTEMS

Scrubber type	Description	Uses
Spray chambers	The simplest, lowest-energy, and most cost-effective type of scrubber. Flue gas is discharged into a chamber, where it is sprayed with water or scrubbing liquid. The scrubbing liquid surrounds the particulate, washing it to the bottom of the chamber. A cyclonic chamber is sometimes used to induce a twisting motion to the gas stream. This motion results in higher gas velocities and more efficient interaction between the particulate and scrubbing liquid.	Removal efficiencies range from 80 to 99 percent for SO <sub>2</sub> , depending upon the type of scrubbing liquid and tower design.
Packed bed	Flue gas is discharged into a vertical or horizontal cylinder that is packed with nonreactive material of a specific shape. Water or scrubbing liquid is introduced at one end of the cylinder opposite to the gas flow and coats the packing material. As the waste gas contacts the packing material, particulate is trapped by the scrubbing liquid and is collected for separation and disposal.	Clogging is common in these types of systems, and they are typically limited to waste gas streams with low particulate concentrations. They are not an effective primary SO <sub>x</sub> control technology
Impingement Plate	This scrubber consists of a long, hollow cylinder filled with horizontally mounted perforated plates. The waste gas is forced upward from the bottom of the cylinder while the scrubbing liquid drips down through the plates. As the liquid has contact with the gas stream, it entraps particulate matter, washing it downward into a collection tank.	Used primarily for collection of larger particulate. Cannot be used as a primary SO <sub>x</sub> management device.
Mechanically aided	Waste gas is directed into a high-speed fan into which water or scrubbing liquid is sprayed. The impact of the water on the fan forms fine droplets that interact with and capture particulate in the gas stream. This liquid is then collected and the particulate allowed to settle out.	Energy intensive and requiring a high degree of maintenance, mechanically aided scrubbers are infrequently used for either particulate or SO <sub>x</sub> control.

## Flue Gas Desulfurization

Even after coal cleaning or HDS, it may be difficult for some stack emissions to comply with current SO<sub>x</sub> limits. The next step is to reduce sulfur content in stack gas, after the fuel has been burned. This is called flue gas desulfurization (FGD), and these technologies can be classified as wet, semidry, or dry processes.

Wet FGD processes spray alkali slurry into the flue gas, forming a weak acid solution that is neutralized by the dissolved alkali. Sulfite and sulfate salts precipitate and are recovered for disposal or sale. In dry FGD systems, either the alkali is mixed into the gas stream or the gas stream passes through a bed of very fine and porous material. SO<sub>2</sub> reacts directly with the solid alkali to form sulfite or sulfate. Water is sprayed into the flue gas in semidry systems. A liquid film forms on the material into which the SO<sub>2</sub> dissolves.

FGD systems can be further subdivided as once-through or regenerable processes. Once-through FGD systems are more commonly used and produce a waste product that must be disposed of properly. Regenerable FGD changes the recovered SO<sub>x</sub> into a useful industrial product, such as elemental sulfur or sulfuric acid. FGD systems are typically used on large electricity-generating boilers. For smaller industrial boilers, the use of low-sulfur fuels is usually a more cost-effective method of reducing SO<sub>x</sub> emissions.

## Once-Through (Nonregenerable) FGD Systems

There are four commonly used nonregenerable FGD systems, three that rely on scrubbing vapors and one that utilizes an absorption process to remove sulfur. Scrubbers work particularly well on SO<sub>x</sub> because sulfur dissolves in water.

Wet lime scrubbers, also called limestone scrubbers, are the most commonly used nonregenerative

Scrubber type	Description	Uses
Venturi (also called gas-atomized spray scrubber)	Flue gas is mixed with water and forced through a small orifice (the venturi) that forces it to accelerate as the orifice narrows and then expand as it widens. This atomizes the mixture and allows the scrubbing liquid to surround and encapsulate the particulate matter. After passing through the venturi, the liquid is separated from the particulate in a cyclone or with a mist eliminator.	Venturi scrubbers are used in applications where high collection efficiencies for fine particulate are necessary. They also are capable of control of volatile organic compound (VOC) and SO <sub>x</sub> emissions.
Orifice (also called entrainment or self-induced spray scrubbers)	The exhaust gas stream flows over the surface of and picks up droplets of the scrubbing liquid. The moist waste gas is directed upward through a duct into a narrow orifice. This causes turbulent flow, atomizing or reducing the size of the entrained droplets. The atomized droplets soak up the particulate matter. Condensate baffles remove the droplets and drop them into a collection tank.	Designed primarily to control fine particulate matter with a diameter of 10 microns or less (PM <sub>10</sub> ). Sox control is a secondary benefit.
Condensation (also called growth scrubber)	Exhaust gas is saturated with water and injected with steam. This creates a supersaturation condition, and the particulate matter serves as condensation nuclei for the excess water vapor. The condensed droplets, which contain the particulate matter, are then removed by a series of baffle plates, a mist eliminator, or similar device.	Installed and operated at facilities to capture particulate that eludes past conventional control devices. Sox control is a secondary objective of this technology.
Charged	These scrubbers impart a positive or negative electrical charge to SO <sub>x</sub> and other particulate in the flue gas. The droplets in the scrubbing liquid are given the opposite charge.	Developed primarily for the collection of fine particulate. Not often used in SO <sub>x</sub> emission management systems.
Fiber bed	Flue gas is sprayed with the scrubbing liquid and passed through layers or mats of fibrous material. The mats or fiber beds capture precipitated particulate and SO <sub>x</sub> . They are often back-washed with the scrubbing liquid to rinse captured particulate out of the fiber beds.	Most often used as a mist eliminator to capture vapors and liquids present in the flue gas rather than to control SO <sub>x</sub> . Unless they are coarsely woven, the mats or beds tend to clog, easily when used to capture solid particulate.

FGD system. Crushed limestone (CaCO<sub>3</sub>) or the more reactive and dangerous lime (calcium oxide) is mixed with water at a concentration of about 10 percent and sprayed into the combustion gases as they leave the burner or furnace and enter a large tank called a spray tower or absorber. The calcium reacts with the SO<sub>x</sub> to form calcium sulfite (CaSO<sub>3</sub>) or calcium sulfate (CaSO<sub>4</sub>). Scrubbing usually takes place after particulate removal, to maximize the reaction rate and reduce the amount of limestone or lime needed. The semiliquid slurry drops to a reaction tank, where it is allowed to settle and thicken before the water is filtered out and the material removed. Some of the slurry can be recycled from the reaction tank and used again in the wet scrubbing process. Wet lime scrubbing can remove up to 90 percent of the SO<sub>2</sub> from most flue gases.

An interesting variation of the wet lime scrubber is a process called seawater scrubbing. Combustion

gases are passed through a tower, where they are sprayed with seawater. As the gases cool, the salts present in the seawater attract SO<sub>2</sub>. The consequently acidic seawater flows into a treatment plant where additional seawater is added to balance the pH. Air is bubbled through the treated water to oxidize the SO<sub>2</sub> to sulfate in solution and to increase the seawater's oxygen content. The seawater is then discharged. Simple and reliable, this low-cost approach can remove up to 99 percent of SO<sub>2</sub> and is especially attractive in developing countries with coastal power plants.

### Other Types of Wet Scrubbers

In addition to SO<sub>x</sub>, scrubber systems have been designed and adapted to control several types of flue gases. These include particulate, hazardous air pollutants, volatile organic compounds, and acid mists.

### Spray Dry Scrubbers

These types of scrubbers inject a fine mist of calcium hydroxide slurry into the flue gas. The hot combustion gases evaporate the water, and the SO<sub>x</sub> reacts with the slurry to form solid particles of calcium sulfite (CaSO<sub>3</sub>) or calcium sulfate (CaSO<sub>4</sub>). These particles fall to the bottom of the mixing chamber or are collected in the particulate emission control system. From 70 percent to 90 percent of SO<sub>x</sub> is removed by using spray dry scrubbers.

### Sorbent Injection

In this process, a dry or moist sorbent such as limestone (CaCO<sub>3</sub>), lime (CaO), hydrated lime (Ca(OH)<sub>2</sub>), soda ash (Na<sub>2</sub>CO<sub>3</sub>), or sodium bicarbonate (NaHCO<sub>3</sub>) is added to the furnace or stack just after the combustion chamber. It can also be mixed with the fuel prior to combustion, depending upon burner configuration. The sulfur reacts with the sorbent to form particulate that is either collected in a separate chamber or collected by the existing air pollution control equipment. This process does not require a significant capital investment and can be easily retrofitted onto existing burners. The level of SO<sub>2</sub> reduction, however, is low to moderate (40–70 percent), and the amount of sorbent needed is relatively large. Several tons of waste (ash, spent and unused sorbent) is produced for each ton of SO<sub>x</sub> removed. This process is considered to be best suited when used in conjunction with low-sulfur coal at older power plants and industrial burners that need only modest levels of SO<sub>x</sub> control.

### Regenerable FGD Systems

Nonregenerable FGD systems are known as throwaway systems. It is more cost-effective simply to discard or limit the scrubbing liquid to a single pass through the system, rather than trying to capture and reuse or recycle it. Regenerable systems, however, use expensive sorbents in the scrubbing liquid, which need to be recovered. This is done by separating the sulfur oxides from the scrubbing medium and using the collected sulfur as a raw material in a commercial product such as sulfuric acid, gypsum, sulfur-based fertilizer, or even elemental sulfur. Although regenerable systems have higher capital and operating expenditure than throwaway systems, there are lower waste disposal costs and revenues from the sale of the recovered sulfur.

Regenerable FGD systems produce an off-gas stream that must be treated in order to remove the sulfur and recover the sorbent. There are about two dozen regenerable FGD technologies commercially

available; they can be generally divided into the following four major groups.

### Aqueous Alkaline Scrubbing

Although limestone (Ca) is the most common scrubbing medium, rather than alkaline metals, aqueous alkaline scrubbing is a postcombustion sulfur control in which the waste gases are scrubbed with a chemical. This method produces slurry that absorbs the SO<sub>x</sub>. The slurry is then oxidized to calcium sulfate (gypsum), which can then be used in the manufacture of wallboard, as an additive to cement, or in other building trades.

The Wellman-Lord process is an aqueous alkaline scrubbing process that can achieve up to 99.9 percent sulfur recovery from combustion gases. It can be divided into two steps. First, the hot flue gases are passed through a prescrubber, where ash, hydrogen chloride, hydrogen fluoride, and SO<sub>3</sub> are removed. The now-cooler gas is mixed with a saturated sodium sulfite (Na<sub>2</sub>SO<sub>3</sub>). The sodium sulfite reacts with the SO<sub>2</sub>, forming sodium bisulfite. The bisulfite solution is collected and fed into an evaporator. Once in the evaporator, the sodium bisulfite is treated with steam to separate or regenerate the sodium sulfite, which is fed back to the flue gases. Steam treatment also releases the SO<sub>2</sub> and converts it to elemental sulfur, sulfuric acid, or liquid SO<sub>2</sub>, depending upon the design of the system.

### Organic Absorption

This is primarily an amine-and-citrate-(Na<sub>3</sub>C<sub>6</sub>H<sub>5</sub>O<sub>7</sub>·2H<sub>2</sub>O)-based process. FGD technology using sodium citrate as the scrubbing medium requires that particulate first be removed and the exhaust gas be cooled. This can be done with a venturi scrubber. The gas is then fed into a tank and mixed with a solution containing citric acid or sodium citrate. Hydrogen sulfide (H<sub>2</sub>S) is added to precipitate recoverable amounts of elemental sulfur and allow the citrate solution to be recycled.

In amine-based processes, nitrogen is the key atom and the SO<sub>x</sub> binds chemically with the scrubbing solution. Methyldiethanolamine (MDEA) and diethanolamine (DEA) are two amines that have been used in these types of systems. SO<sub>x</sub>-enriched solution flows to a tank, where the sulfur is precipitated and recovered and the amine solution captured for recirculation. A large quantity of SO<sub>x</sub> can be removed by these types of solutions, and the process can be operated for long periods without major loss of SO<sub>x</sub> removal efficiency.

Citrate and amine systems are not commonly used where high volumes of SO<sub>x</sub>-enriched waste

gases are produced such as electric utilities. They are more commonly applied at oil refineries and other places where SO<sub>x</sub> waste gas streams are present, but not in large amounts.

### Reactive Adsorption

Regenerative scrubber systems pass combustion gases through a ceramic or metal honeycomb or lattice coated with a zinc, copper oxide, or alkali metal. Honeycomb structures are used to reduce backpressures and to ensure adequate contact between the gas and reactive metal. The sulfur dioxide is absorbed onto the catalyst and is washed off using a methane-saturated water, which adds hydrogen to sulfur dioxide and forms hydrogen sulfide. The H<sub>2</sub>S formed in the hydrotreating process is then combined with additional sulfur dioxide to produce elemental sulfur.

Hydrogen sulfide occurs naturally in crude oil and natural gas, and its removal is a critical step in the refining process. This is most frequently done by converting the H<sub>2</sub>S into elemental sulfur. Approximately 65–70 percent of the sulfur is recovered. Therefore, two or more catalytic stages are used in series, with each stage recovering one-half to two-thirds of the incoming sulfur. The number of catalytic stages depends upon the level of recovery required, with about 95–97 percent recovery possible. Most modern plants are built with two to three catalytic stages. From the condenser of the final catalytic stage, the combustion gases, containing H<sub>2</sub>S, SO<sub>2</sub>, sulfur vapor, and traces of other sulfur compounds, pass to some form of treatment, usually a wet scrubber.

### Physical Adsorption (Activated Carbon)

This method involves passing the exhaust gas through a bed of activated carbon. The carbon captures and removes the sulfur and other impurities from the gas. This process can remove up to 95 percent of SO<sub>2</sub> and more than 80 percent of NO<sub>x</sub>. It can be used alone or in conjunction with other FGD systems and has been successfully applied on a commercial basis in Europe and Japan for SO<sub>x</sub> and NO<sub>x</sub> control of emissions from coal combustion and waste incineration. A strong advantage of activated carbon is that it captures nearly all impurities present in combustion gases including particulates, SO<sub>2</sub>/NO<sub>x</sub>, mercury, lead, and dioxins. Its main drawback is the high cost associated with the chemical or physical regeneration of the carbon after it has become saturated with recovered contaminants and the recovery of the sulfur. Although carbon is the most commonly used adsorbent, alu-

mina, zeolites, and polymers have been used successfully in other systems.

See also AIR POLLUTION; MEUSE VALLEY DISASTER; NO<sub>x</sub>; PARTICULATE.

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**Superfund sites** On December 11, 1980, President Jimmy Carter signed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), which had previously been passed by the U.S. Congress. The bill was written largely in direct response to the Love Canal, New York, environmental disaster, but that was really just the last straw in a growing public response to the numerous environmental disasters throughout the United States. CERCLA directed the EPA to develop the Superfund program, which would address abandoned, accidentally spilled, or illegally dumped hazardous wastes that pose a threat to the environment and human health. Superfund was designed to manage emergencies that attracted national attention—such as at Valley of the Drums; Bullitt County, Kentucky; and the Chemical Control Corporation explosion in Elizabeth, New Jersey—and also less prominent situations involving malingering and dangerous pollution. In addition, Superfund was responsible for conducting research on the processes of pollution migration; developing new technologies to treat, store, and dispose of wastes; and involving communities near hazardous



sites in the processes of delineation and remediation of the sites.

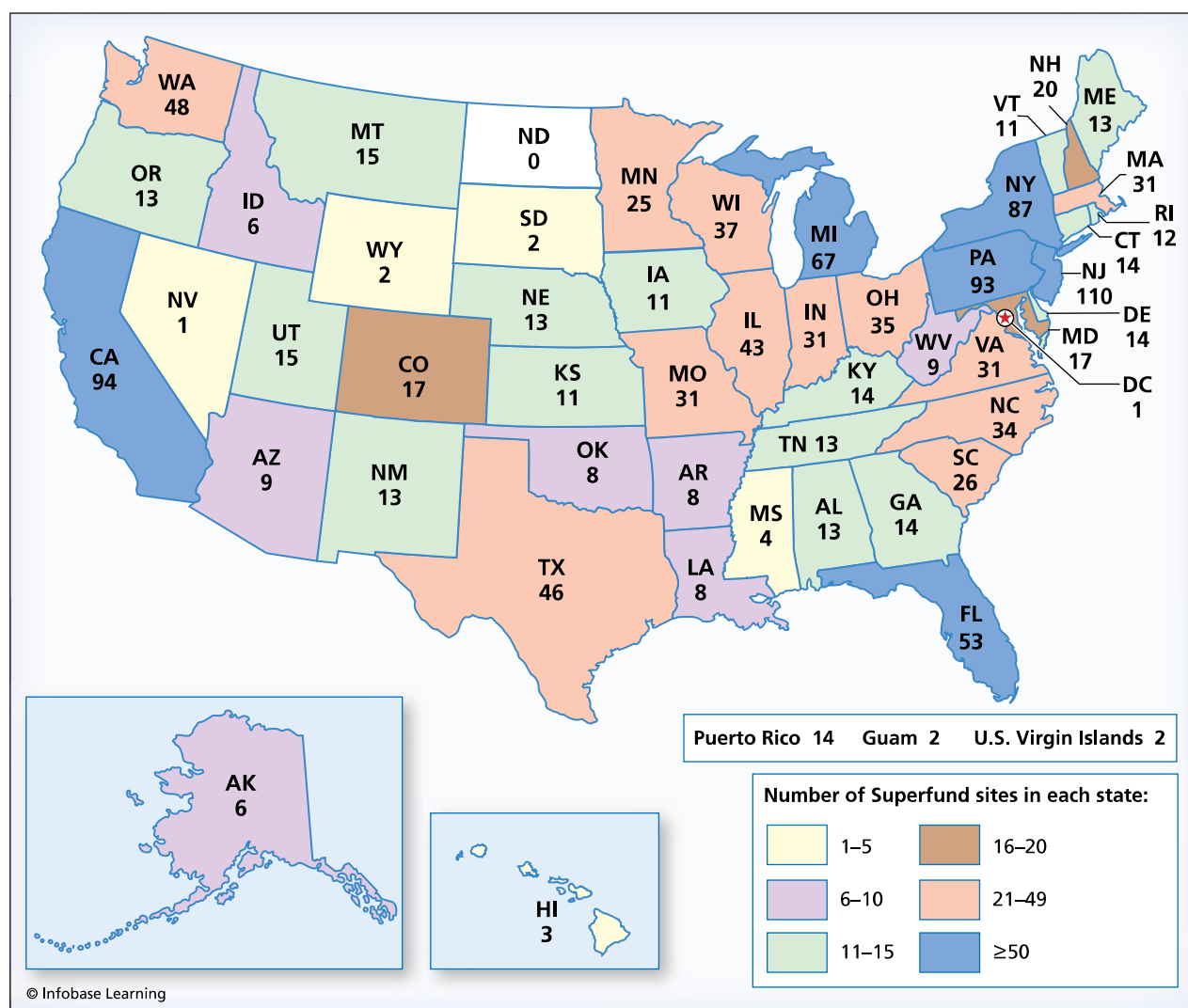
The remediation of sites with severe pollution problems is very expensive. One of the main functions of CERCLA was to create a tax on the chemical and petroleum industries to raise funds to respond to the releases or potential releases of hazardous substances to the environment. Over the first five years, more than \$1.6 billion was collected and placed in a trust fund to clean up the identified hazardous waste sites (Superfund sites). That trust fund was increased to \$8.5 billion through the Superfund Amendments and Reauthorization Act (SARA), an amendment of CERCLA that was passed on October 17, 1986. In addition, the EPA established an enforcement program as part of

Superfund that secured nearly \$24 billion in the first 25 years through seizures of assets and fines.

### CERCLA AND SARA

The original CERCLA bill of 1980 had three main functions:

1. to establish regulations for closed and abandoned hazardous waste sites
2. to establish liability for the parties responsible for releasing hazardous waste
3. to establish a trust fund to remediate sites where no responsible party exists



**Map of the United States showing the number of active Superfund sites by state in 1992** (*New Jersey was and is the state with the most sites*)

CERCLA further authorizes two actions depending on the nature of the problem:

1. emergency removals where there is an immediate threat to human health and the environment
2. long-term remediation to reduce permanently the dangers from the release or potential release of hazardous waste that does not pose an immediate threat

These sites must be listed on the EPA National Priorities List (NPL) prior to remediation. The SARA bill of 1986 added several major amendments to CERCLA in addition to increasing the budget including:

1. It encouraged the development of permanent remedies and innovative technologies in the remediation of hazardous waste sites.
2. It required the Superfund program to model the other state and federal environmental regulations in their actions where appropriate.
3. It provided additional enforcement and settlement measures for violators.
4. It increased state involvement in the Superfund process.
5. It shifted the Superfund focus more strongly toward human health threats.
6. It increased the involvement of the local residents in remediation goals and procedures.

### ESTABLISHING A SUPERFUND SITE

The EPA has established a Hazard Ranking System (HRS) to evaluate whether a particular site should be placed on the National Priorities List (NPL), which makes it a Superfund site. The HRS does not determine priority; it simply assigns a score based on certain factors, which then aids the decision process. The factors in the HRS are grouped into three categories:

1. the probability that the particular site has released or will release hazardous substances into the environment
2. the quantity, relative toxicity, and physical characteristics of the waste repository

3. the number and disposition of people and sensitivity of the environment that are or would be affected by a release

Four pathways of release can be considered under the HRS:

1. groundwater release including impact on drinking water
2. surface water, including drinking water, release impacts on the food chain and sensitive environments
3. oil release including local population and sensitive environments
4. atmospheric release including local population and sensitive environments

The procedures for establishing a Superfund site are well defined. The first step entails a preliminary assessment and site inspection. The preliminary assessment is a review of the information on a site and its surrounding area to determine whether it poses a threat to human health and/or the environment. The report is either to recommend further investigation or not. If the preliminary assessment finds reason for concern, the next step is site inspection. This procedure is designed to collect the data necessary to perform scoring using the HRS. The inspection includes visiting the site to provide a full visual and quantitative analysis, including the collection of environmental and waste samples for chemical analysis. This inspection is also designed to determine whether and how far the pollution has spread from the source. The results from this analysis and consequent HRS score are used to determine whether the site should be placed on the NPL and undergo remediation.

If the site in question meets the requirements for NPL, the next step is to perform a remedial investigation and feasibility study (RI/FS); both aspects are studied concurrently. The remedial investigation is designed to characterize the site, determine the type of hazardous waste, evaluate the risk to public health and the environment, and evaluate the cost and effectiveness of the proposed treatment plan. The feasibility study evaluates alternative remedial methods and actions. Investigators must complete five distinct phases:

1. scoping
2. site characterization

3. evaluation of alternatives
4. treatability evaluation
5. detailed analysis

Scoping involves the initial physical delineation of the study area, determination of remedial objectives and any interim procedures, and determination whether the site should be parceled or treated as a single unit. Detailed scoping objectives are addressed once the broad strategies are determined. These activities typically include determining the regulations involved in the remediation Applicable or Relevant and Appropriate Requirements (ARARs), determining the course of action and data requirements to pursue it, assembling the technical advisory committee, and preparing the entire plan of action including scope of work, sampling and analysis, health and safety, and community relations.

The site characterization phase includes field sampling of water, soil, and air and chemical analysis thereof. Proper protocol calls for a preliminary site characterization report in the early stages of the study and a full remedial investigation report at the end. This phase also includes a feasibility study of the planned technology to be applied and a baseline risk assessment for both human health and the environment.

The phase of development and screening typically begins during the scoping phase as soon as the objectives of the remedial action become apparent. Once the objectives are known, treatment, recovery, and containment options to address them can be proposed. The technologies involved in these processes might then be evaluated or screened as to their effectiveness and implementation in the particular situation, as well as their cost. Finally, alternatives to the standard operating procedures are considered to optimize the remediation efforts. This phase works hand in hand with the treatability investigations phase, which is really a refinement of the former. This phase just adds supporting information to alternatives to specify them further, and it streamlines the procedures to minimize costs.

The final step is the detailed analysis, which is the true plan of action for the site. It addresses nine criteria:

1. protection of public health and the environment
2. compliance with state and federal regulations (ARARs)
3. long-term effectiveness of remediation

4. reduction of the toxicity, mobility, and/or volume of waste
5. short-term effectiveness of remediation
6. feasibility of implementation
7. cost of remediation
8. acceptance by state authorities
9. acceptance by the impacted community

### SUCCESS OF SUPERFUND

In spite of its critics, the Superfund program is considered to have been highly successful. Compared to the situation before 1980, public health is vastly better protected as a result of this program. By the end of 2006, some 1,006 Superfund sites around the United States were considered completed, 64 percent of those on the National Priorities List. At that point, there were 653 ongoing remediation projects at 414 Superfund sites. The average time required to remediate a Superfund site is 12–15 years with monitoring continuing well after remediation is complete. It is estimated that there are 4,500 sites in the United States that will make the Superfund list during the life of the program, with a projected cost of remediation of about \$75 billion. In addition to the long-term projects, there were 294 emergency response actions that addressed immediate threats in 2006 alone with a total of 4,020 between 1981 and 1996. These actions primarily involved the cleanup and removal of hazardous substances from spills and accidental releases. The remediation of many of these Superfund sites created productive properties in key urban locations, revitalizing areas that suffered because of the environmental issues. They now generate tax revenues and serve their communities. Redevelopment of these Superfund properties, in total, has generated more than 80,000 on-site jobs and an annual income of \$2.7 billion. Although the Superfund program has had its errors, in general, it is a very successful program.

See also INORGANIC POLLUTANTS; LANDFILL; ORGANIC POLLUTANTS; POINT SOURCE AND NON-POINT SOURCE POLLUTION; SOIL.

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**Tasman Spirit oil spill Port Karachi, Pakistan (July 27, 2003)** *Water Pollution*

Karachi, a port city northwest of the Indus River delta, is the most populous city in Pakistan and quickly becoming the most populous area in the world. A developing megacity, the Karachi metropolitan area officially has 14 million residents, but unofficial tallies estimate the population, which tripled between 1980 and 2007, as closer to 20 million. This huge number of people is packed into a little more than 1,350 square miles (3,500 km<sup>2</sup>). The explosive growth of Karachi is the result of a vibrant economy based both on heavy industry of shipbuilding, textiles, steel, oil, and chemical manufacturing, and a strong business service sector including software development, banking, and finance. As with most megacities, the energy needs of Karachi are enormous and are partially met by a nuclear-powered electricity-generating facility, wood, and some solar sources, but oil is the primary fuel. Although Pakistan has some of its own reserves, most of the oil is from other nearby Middle Eastern countries such as Iraq, Iran, and Saudi Arabia.

The harbor is the reason the economy thrives in Karachi, and the long adjoining sandy beaches provide enjoyment and relief from the long summer heat for the residents. Summer temperature extremes also are moderated by landward ocean breezes from the Arabian Sea that cool the city, blow away its air pollution, and keep the humidity low. Karachi Harbor is protected from the full effect of storms and rough water by these same beaches as well as by a series of semiencircling barrier islands, river deltas, and rocky sea cliffs, which project off the mainland and into the ocean.

It is through Karachi Harbor that Pakistan receives most of its oil, via tankers making the short trip from the Persian Gulf southward through the Straits of Hormuz and along the Iranian coast. This was the route that the Maltese tanker *Tasman Spirit* was following when it ran aground at the entrance to Port Karachi in the early afternoon hours of Sunday, July 27, 2003.

### BACKGROUND

Named after Abel Janszoon Tasman (1603–59), the Dutch explorer and the first European to discover Tasmania and New Zealand, the *Tasman Spirit* was a single-hulled 87,584 deadweight tonnage (DWT) tanker built in 1979. It was operated under a Maltese flag of convenience and was registered to the Greek company Assimina Maritime Ltd. Under charter by the government-owned Pakistan National Shipping Corporation, the ship was carrying 74,700 tons (67,800 metric tons) of light Iranian crude oil, which was scheduled for delivery to Pakistan Refinery Ltd., a government-owned oil terminal and processing center. Another 485 tons (440 metric tons) of heavy fuel oil, or Bunker C, used in the operation of the engines and other shipboard systems, was present in *Tasman Spirit*'s aft storage tanks. *Tasman Spirit* was nearing the end of its useful life, and because of the single hull and other safety issues, it had been prevented from entering U.S. and most European ports. As a result, the Pakistan National Shipping Corporation was able to negotiate an excellent charter price from the owners, and it continued to sail up and down the coast carrying oil.

### THE ACCIDENT AND SPILL

At the entrance to the shipping channel, the harbor pilot boarded *Tasman Spirit* in a driving monsoon rain. As the ship slowly entered the harbor, it was pushed out of the main shipping channel by the strong winds and waves and went aground on a sandy shoal. The harbor pilot was initially blamed for failing to keep *Tasman Spirit* on course, but he claimed that the ship was correctly positioned. The cause was the channel, which had not been dredged to its charted depth and was too shallow to accommodate a vessel of this size. Although no oil had spilled when the *Tasman Spirit* went aground, it was blocking the entrance to the harbor and represented a potentially major public safety, environmental, and economic threat.

The initial response plan to deal with the grounding was to attempt to pull *Tasman Spirit* off the shoal and return it to the main channel. The single tug assigned to the task, however, was not strong enough to move the ship. Larger, more powerful tugs were available in another harbor only a short distance away but for some reason were not requested to assist in the refloating effort. Three attempts were made in heavy rains and high winds over the next week until August 4, when it became apparent that the stress of being repeatedly shoved and rocked against the shoal was starting to affect the structural integrity of the ship.

The Karachi Port Trust (KPT), the operators of the harbor, decided to initiate a lighterage operation by transferring the oil from the grounded ship to smaller tankers. A lighter is a small, flat-bottomed barge or tanker used in the loading and unloading of ships and in transporting cargo over short distances. These smaller lighters or tankers were to take on the oil from *Tasman Spirit* and off-load it at the nearby Pakistan Refinery Ltd., the designated receiving facility. Although the KPT stated that no environmental impacts had yet occurred, it was around this time that other vessels using the harbor began to report the smell of oil in the air. By August 11, more than 22,000 tons (20,000 metric tons) of oil had been transferred from the stricken vessel, including most of its nautical fuel, the much heavier and more environmentally damaging Bunker C oil. The lighterage operation, however, was proceeding slowly, with only 6,000 tons (5,400 metric tons) every 36 hours transferred from *Tasman Spirit* to a barge, and then from the barge to a larger tanker for transport to the refinery.

By the evening of August 13, there were major cracks in the hull of *Tasman Spirit* and in order to ensure the safety of those onboard and nearby,

lighterage operations were suspended. During the evening, the *Tasman Spirit* began to groan and shudder, and, early in the morning of August 14, it split in two. Over the next four days 29,700 tons (27,000 metric tons) of oil was slowly released into the waters of Karachi Port. Another structural failure took place on August 22 and released about 220 tons (200 metric tons). On September 4, some five weeks after grounding of the *Tasman Spirit*, the final cargo hold ruptured. In all, 33,000 tons (30,000 metric tons) of oil is estimated to have spilled from *Tasman Spirit*, and the discharge of this quantity of oil in such a confined area ranks the spill as the largest crude oil release since the *Sea Empress* discharged more than 77,000 tons (70,000 metric tons) of oil along the coast in southwestern Wales.

The oil released from *Tasman Spirit* was light Iranian crude that contained a high concentration of aromatic hydrocarbons. Aromatic hydrocarbons are a class of chemical compounds that contain one or more benzene rings and have strong, pungent aromas, usually from impurities. They readily evaporate, and exposure to aromatic hydrocarbons can have significant health effects. Although crude oil is generally a mix of many petroleum compounds, this particular type of Iranian crude was made up of 34 percent light and heavy naphtha (various volatile aromatic hydrocarbon mixtures), 4 percent gasoline, and 1.4 percent sulfur. Its American Petroleum Institute (API) viscosity was  $-20^{\circ}\text{F}$  ( $-29^{\circ}\text{C}$ ), making it "thin" and readily flowable.

As *Tasman Spirit* oil entered the water, it spread rapidly and began to evaporate quickly, aided by an  $85^{\circ}\text{F}$  ( $29^{\circ}\text{C}$ ) temperature in Karachi and the monsoon winds and rains that were stirring up the normally quiet harbor waters. The area to the west of *Tasman Spirit*'s grounding contains extensive stands of mangroves and is an important habitat for sea turtles, dolphins, porpoises, and whales, as well as several species of lizards and sea snakes. More than 200 species of fish are present in these waters, and they serve as a vital component of the local economy. To the east of the leaking wreck, some 50 different types of both resident and migratory birds inhabit the area and utilize the associated tidal estuaries, river and creek systems, mudflats, and sand beaches as both nesting and feeding grounds.

### THE OIL SLICK AND CLEANUP

The majority of the oil quickly contaminated Clifton Beach, Karachi's most popular shoreline. Ten miles (16 km) of shoreline was closed, and an additional 77 square miles (200 km<sup>2</sup>) was affected by the spill.

The 300,000 people who lived within 0.6 mile (1 km) of this important stretch of coastline faced a closed and contaminated beach; black waves carrying the bodies of dead sea turtles, sea snakes, and birds; and the overpowering smell of oil. The Pakistani government responded with the aerial application of dispersants, both along the beach and onto the open waters of the harbor. The beach spraying stopped, however, when local residents complained of nausea, headaches, and other health effects from inhalation of airborne dispersants. Oil that washed onshore was scraped and bulldozed into piles, but they were often left in place for many days because a suitable land-based disposal facility for the oily waste could not be found. During periods of low tide, government cleanup crews plowed under the upper layer of oily sand along the beach so it could no longer be seen. Only about 1 percent of the oil was recovered, and the beach was not reopened until October. The cleanup proceeded more efficiently in the harbor, with booms placed around the slick and across the entrance to sensitive waterways and habitats. These devices recovered 154 tons (140 metric tons) of oil.

One of the most important aspects of the oil spill from *Tasman Spirit* was its effect on local air quality. The high temperature, strong winds, and intense waves, which increased the spread of the oil, also hastened its evaporation. The gases and vapors emanating from the oil moved landward, pushed by the normally cooling and refreshing onshore breezes. Of the almost 30,000 tons (27,000 metric tons) of oil released from *Tasman Spirit*, an estimated 12,100 tons (11,000 metric tons) evaporated and settled over the coastal residents. Concentrations of volatile organic compounds (VOCs) measured in the air downwind of the wreck ranged from 44 to almost 180 ppm and produced an odor until early September. In the United States, no standards have been set for VOCs in nonindustrial settings, but the Occupational Safety and Health Administration regulates hydrocarbon-related VOCs to levels ranging from 0.1 to 0.75 ppm. Hospitals and medical camps established by local officials treated hundreds of people for headaches, nausea, and dizziness. There were 17 schools in the vicinity closed for up to a week, and the long-term health effects on exposed residents are still being studied.

### THE AFTERMATH

An official estimate of the amount of marine and animal life killed by the oil was not made. Later studies confirmed that bottom sediments were contaminated and that elevated levels of hydrocarbons

were present in turtle eggs and the tissues of fish and other types of marine life. Fishing in the area of the spill and within an almost-six-mile (9.3-km) radius was banned for three months, and fishermen lost a substantial portion of their income that year. Yields in subsequent years were well below normal, and several studies estimated that it would be five to seven years before prespill catch volumes were restored.

Pakistan is not a signatory to the International Oil Pollution Compensation (IOPC) Fund, a 1992 agreement established as a result of the International Convention on Civil Liability for Oil Pollution Damage and funded by a small per-gallon tax on each gallon of oil handled by the member countries. The fund covers claims made by any of its 98 member states, in excess of compensation provided by shipowners and their insurers. The fund pays for cleanup, damage to property, as well as consequential and economic losses such as from fishing bans. Funding is also provided for activities to prevent or minimize pollution, such as purchasing and equipping oil spill response boats. Pakistan fined the owner of the tanker \$200,000 and submitted claims to *Tasman Spirit*'s insurance company to recover cleanup costs, but it is unlikely that there will be enough money to compensate local residents for their illnesses or loss of income as a result of the spill.

See also DELTA; NAPHTHALENE; OIL SPILLS; SEA EMPRESS OIL SPILL; VOLATILE ORGANIC COMPOUND.

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**TCA (trichloroethane)** The term *TCA* refers to 1,1,1-trichloroethane, a very common organic compound. The problem is that 1,1,1-trichloroethane is also sometimes referred to as 1,1,1-TCE, whereas TCE is really trichloroethylene. Even more confusing is that both were restricted or banned around 1989–96 because of danger to public health and the environment. It is not surprising that the two chemicals are confused, causing problems for citizens and environmental professionals alike. TCA is also known in industry as Chloroethene, Methylchloroform, Aerothene TT, Algylen, Alpha-T, Chlorten, Gemalgene, Genklene, Dowclene, Solvent 111, Trichloran, and Inhibisol. It is a widely used chemical that has been identified in 823 of the first 1,662 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priority List) where it was tested. As the result of the wide distribution of TCA and its adverse health effects, it has been ranked as the 97th most dangerous pollutant on the top 275 of the 2007 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USES, AND PRODUCTION

TCA is a synthetic organic colorless liquid with a sharp, sweet odor that evaporates quickly. It was invented in 1840, but peak production did not occur until the mid-1950s through 1995. At that point, its production was restricted and later banned on January 1, 2002, under the terms of the Montreal Protocol because it degrades ozone. TCA was primarily used as a solvent to dissolve other compounds. It was used as a vapor degreaser for metal products, for cleaning of precision instruments, for textile processing and dyeing, and in aerosols. It is also used as a chemical intermediate in the manufacturing of certain organic chemicals such as vinylidene chloride, as a coolant and lubricant in metal cutting oils, and in home applications such as drain cleaners, spot removers, shoe polish, food packaging, photographic film, aerosol propellant, glues, and inks. There were also agricultural uses for TCA such as fumigation of strawberries and degreening of citrus fruit and as a solvent for several varieties of pesticides. In 1989, 34 percent of TCA usage in the United States was for vapor degreasing, 12 percent for cold cleaning, 10 percent for aerosols, 8 percent for adhesives, 7 percent as a chemical intermediate, and 5 percent in coatings. The remaining 24 percent was used for a variety of miscellaneous purposes.

Domestic demand for TCA was 700 million pounds (318 million kg) in 1988, 705 million pounds (320 million kg) in 1989, and 735 million pounds (334 million kg) in 1993. Worldwide production in 1988 was 735,000 tons (678,000 metric tons).

Demand and production fell off sharply in 1996 and ended completely by 2002.

### ENVIRONMENTAL RELEASE AND FATE

TCA is mainly released as a point source pollutant from spills and leaks in manufacturing and production plants, during transportation, and in storage. Once released to soil, most TCA simply evaporates because of its high volatility. That which percolates into the soil adheres well to organic matter in proportion to the organic carbon content. It does not adhere well to clays, sand, or any other particles. As a result, it readily leaches from the soil into the groundwater system, where it is frequently found. TCA is very persistent in the natural environment. In one study, after 27 weeks in subsurface soils, no degradation was observed. Even biodegradation is slow, with an estimated removal half-life of 231 days under anaerobic field conditions.

If released to water, most TCA simply evaporates. Under laboratory conditions, removal half-life by evaporation ranged from less than one hour to several hours. In natural systems, removal half-life by evaporation was three to 29 hours for rivers, 5.1–10.6 days for ponds, and 3.8–12 days for lakes. Otherwise, that which does not evaporate degrades very slowly with a removal half-life of six months or more. TCA is also relatively stable in air. It breaks down rapidly by direct photolysis in the stratosphere, where it attacks and breaks down ozone. It was primarily for this reason that it was banned.

According to the EPA Toxic Release Inventory, some 222,000 pounds (101,000 kg) of TCA was released to water and 812,000 pounds (369,000 kg) of TCA was released to land between 1987 and 1993. The largest release by far was in California, followed by Georgia, Arizona, Indiana, Virginia, and Utah. The releases resulted mostly from steel and iron production, aircraft manufacturing, and miscellaneous manufacturing.

### HEALTH EFFECTS FROM EXPOSURE

Exposure to TCA produces several adverse health effects. Acute exposure to TCA fumes causes dizziness, loss of coordination, and lightheadedness, but the symptoms disappear quickly once the chemical is removed. If the acute exposure is longer and at higher levels, symptoms may include loss of consciousness; drop in blood pressure; damage to the liver, nervous system, and circulatory system; and, in extreme conditions, even death. Chronic exposure can also cause liver, nervous system, and circulatory system damage.



## REGULATIONS ON HUMAN EXPOSURE

Federal agencies regulate worker and general exposure to TCA as the result of these health risks. The EPA limits the amount of TCA in drinking water to 0.2 part per million (ppm) under the Safe Drinking Water Act. They further require the reporting of any environmental release of 1,000 pounds (454 kg) or more to the National Response Center. The Occupational Safety and Health Administration (OSHA) restricts the amount of TCA in workplace air (PEL) to 350 ppm for an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) has set the same general exposure limit (REL) as OSHA and a designation of immediately dangerous to life and health (IDLH) for any exposure of 700 ppm in workplace air.

See also ORGANIC POLLUTANTS; OZONE AND CHLOROFLUOROCARBONS; POINT SOURCE AND NON-POINT SOURCE POLLUTION; SUPERFUND SITES; TCE.

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**TCB (trichlorobenzene)** TCB has three isomers based on the position of the chlorine atom, 1,2,3-TCB, 1,2,4-TCB, and 1,3,5-TCB. The most common of these is 1,2,4-TCB, which is also known as Hostetex L-PEC and Trichlorobenzol. The TCBs were widely used primarily in industrial applications as well as some specialized consumer applications, but 1,2,3-TCB and, to a lesser extent, 1,2,4-TCB have been phased out over the years because of the adverse health and environmental effects associated with their usage. They are still used in some specialized applications but not nearly to the degree they were in the past. Exposure may still result from the

manufacturing applications and leaking toxic landfills but also from leaking of old electrical devices where they were commonly used as coolants. 1,2,4-TCB still has many sources of exposure but is less dangerous. 1,2,3-TCB was rated number 116 of the 275 substances on the 2007 CERCLA Priority List of Hazardous Substances and 1,2,4-TCB was rated number 203.

## PROPERTIES, USES, AND PRODUCTION

1,2,4-TCB is an aromatic colorless liquid at room temperature but a rhombic crystalline solid at slightly lower temperatures (below 63°F, or 17°C), whereas 1,2,3-TCB occurs as white crystals. 1,2,4-TCB is used as both a solvent and a chemical intermediate in chemical manufacturing; as a component of dielectric fluids, transformer coolants, and lubricants; as a degreasing agent; in septic tank and drain cleaners and wood preservatives; and as a herbicide for aquatic weed control. It was formerly used as a soil treatment for termite control. 1,2,3-TCB is used as an intermediate in the production of various organic chemicals, but many of its other applications, including as a solvent for high-temperature melting products (glass, etc.), a dye carrier for polyester material, a coolant for electrical installations, and an organic insecticide for termite control, have been largely phased out.

The U.S. Environmental Protection Agency (EPA) estimates that domestic production of 1,2,4-TCB ranged from 3 million to 8 million pounds (1.36–3.6 million kg) in 1983 with 3 million pounds (1.36 million kg) of imported chemicals. Estimated global production of TCB was 15,730 tons (14,300 metric tons) in 1995.

## ENVIRONMENTAL RELEASE AND FATE

TCB primarily exists as a point source pollutant emitted directly from industry or from spills and leaks during transport, storage, and disposal. It also occurs as a nonpoint source pollutant from its use as a herbicide and pesticide, from air pollution fallout, and from leakage from common electrical devices, among other sources. TCB is released into the atmosphere through evaporation, some burning processes, and as industrial emissions. It reacts with photochemically produced hydroxyl radicals in air with an average removal half-life of 18.5 days to several months, although it may also be removed to the surface by precipitation. If released into the soil, part of it will evaporate. The remainder adsorbs strongly to the organic particles and less strongly to clay, where it has very low mobility. In sandy soils,

it may leach into the groundwater system in some cases, and it has been detected in some drinking water systems. TCB undergoes slow biodegradation as a function of temperature primarily under aerobic conditions. It may also biodegrade under anaerobic conditions with a relatively quick removal half-life of 30.5 days or less, but with a significant lag time of up to 72 days before the process begins. There are no data on the removal of TCB from groundwater.

If it is released into surface water, an appreciable amount of TCB can evaporate depending upon conditions. The removal half-life of TCB by evaporation ranges from 4.2 hours for a river to 11–22 days for seawater. That which remains readily attaches to particles and settles into the sediment, where it undergoes biodegradation. Degradation of TCB by exposure to sunlight is extremely slow (estimated removal half-life of 450 years). Actual removal half-lives from rivers range from 1.5 to 28 days. TCB has been detected in several major surface water bodies including Lake Ontario; Lake Huron; Niagara River, New York; and Grand River, Quebec. TCB can be strongly bioconcentrated in aquatic organisms with measured concentrations ranging from 51 to 2,800 times ambient levels, posing a health hazard to humans and other predatory animals. It is highly toxic to aquatic organisms.

The EPA Toxic Release Inventory of 1987–93 records the industrial release of 180,000 pounds (81,818 kg) of 1,2,4-TCB to the environment, about 87 percent of which was to water. The state with the highest release was North Carolina, followed distantly by Virginia, Georgia, West Virginia, and New York, in decreasing order. The reported industrial release was 57,704 pounds (26,229 kg) in 2005.

### HEALTH EFFECTS FROM EXPOSURE

Both 1,2,3-TCB and 1,2,4-TCB have produced significant adverse health effects in both humans and laboratory animals. TCBs are considered to be moderately toxic through both inhalation and ingestion. Acute exposure produces moderate to severe irritation of the skin (including chloracne), eyes, throat, and mucus membranes, as well as some central nervous system effects such as lethargy and dizziness. At high dosage, laboratory animals experienced damage to the liver, kidneys, adrenal glands, pancreas, and reproductive organs to varying degrees. Long-term exposure results in decreased body weight and moderate to severe damage to the kidneys, liver, spleen, reproductive organs, adrenal glands, and thyroid, as well as less severe effects to the central nervous system and immune system. Humans also developed anemia and other blood changes. When pregnant

animals were exposed to TCB, they showed the effects of exposure, but only some of the offspring showed effects. Some groups showed decreased birth weight and size and damage to the eyes.

Although TCB is not evaluated as a carcinogen by any of the major agencies, some studies suggest that it may increase the likelihood of cancer. Laboratory animals showed great increases in liver cancer and metastatic pulmonary tumors. Many of the animals died of cancer.

### REGULATIONS ON HUMAN EXPOSURE

As a result of the risk of adverse health effects and damage to the environment, federal agencies have set exposure limits for TCB. There are some regulations for 1,2,4-TCB, but the rest of the isomers remain relatively unregulated. The EPA set a maximal level of 70 parts per billion (ppb) of 1,2,4-TCB in drinking water under the Safe Drinking Water Act. They also require the reporting of any spill of one pound (0.45 kg) or more to the National Response Center. The National Institute of Occupational Safety and Health (NIOSH) set maximal levels (ceiling) of five parts per million (ppm) of 1,2,4-TCB in workplace air for a 10-hour-workday, 40-hour workweek.

*See also* BIOACCUMULATION AND BIOMAGNIFICATION; LANDFILL; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**TCE (trichloroethylene)** TCE is a chlorinated hydrocarbon solvent that has been the subject of numerous severe environmental problems. It was widely considered the most effective of the chlorinated solvents from the 1930s through the 1950s, when other solvents became available. Other names and commercial names for TCE are Acetylene trichloroethylene, Algylen, Anameth, Benzinol, Chlorilen, CirCosolv, Germalgene, Lethurin, Perm-a-chlor, Petzinol, Philex, TRI-Plus M, and Vitran. Halothane replaced TCE in many medical procedures in 1956. As a result of emerging health concerns, it was slowly removed from the U.S. and international markets, when it was banned throughout most of the world from food and pharmaceutical applications. A total ban on TCE for public consumption was not achieved until the 1980s, when, surprisingly, the final usage was as an analgesic in obstetrics, and it was implicated in fetal death. The military also phased out TCE, using a total of only 11 gallons (40 L) in 2005.

Of the first 1,428 hazardous waste (Superfund) sites identified by the U.S. Environmental Protection Agency (EPA) as serious enough to be on the National Priorities List (NPL), 861 have tested positive for TCE. This is a very high percentage, and not all sites have been tested. Because of its health effects and widespread distribution, TCE has been ranked the 16th worst pollutant of the top 275 on the 2009 CERCLA Priority List of Hazardous Substances.

### PROPERTIES, USES, AND PRODUCTION

TCE was first invented in Great Britain in the 1920s as a revolutionary replacement for chloroform and ether. TCE is a clear, colorless, nonflammable liquid that has a sweet smell and quick evaporation. It is less toxic than chloroform and less flammable than ether, and, as a result, it was used as a volatile anesthetic and analgesic in medical procedures. It also has other uses as a solvent for numerous organic compounds and as a degreaser for metal parts. It was used in a variety of applications from extraction of oils, spices, and caffeine from plant material to dry cleaning solvent. TCE has been found in some common household items such as typewriter correction fluid, paint remover, adhesive, and spot remover. In many of these items, it has been totally removed, and in others it has been reduced.

On average, as of 2006, the United States used about 100 tons (45.5 metric tons) per year.

### ENVIRONMENTAL RELEASE AND FATE

TCE is mainly released to the environment as a point source pollutant from industrial manufacturing, transportation, and storage as spills or leaks, although it has been purposefully dumped in the past. When TCE enters the environment, its stability depends upon the situation. It evaporates easily and is significantly broken down in air within one week, possibly to phosgene, a lung irritant. Under high heat, it breaks down to phosgene and dichloroacetylene. In the human body, TCE may break down to dichloroacetic acid (DCA) and trichloroacetic acid (TCA), both of which are toxic to animals and possibly humans. TCE degrades in surface waters in days to weeks. The real problem with TCE occurs in the subsurface. It cannot readily evaporate from groundwater because of the lack of air and, therefore, breaks down very slowly. TCE is even more stable in soil, so it can persist almost indefinitely. From soil, it can be washed into groundwater during rain or thaw. TCE cannot be removed from water by most conventional methods used in wastewater treatment. The most common method is pump and treat using air stripping or activated charcoal. Bioremediation using certain genetically altered bacteria has also proven effective.

### HEALTH EFFECTS FROM EXPOSURE

TCE produces a variety of physiological effects when inhaled and with long exposure to the skin, especially if the skin is broken. It primarily depresses the central nervous system as do other anesthetics and produces symptoms similar to those of alcohol intoxication. Symptoms begin with headache and dizziness, progressing to confusion and then unconsciousness. These symptoms of short-term exposure dissipate after a few hours, although they may last longer if combined with alcohol. If exposure is too great, the respiratory and circulatory depression that results can be fatal. Cardiac sensitization to certain drugs can result in dangerous arrhythmias with TCE exposure as well. Frequent, repeated exposure to TCE can lead to long-term or permanent damage to the central nervous system. Symptoms include sleeplessness, fatigue, anxiety, irritability, personality disorders, and, later, poor coordination, difficulty in thinking, and loss of short-term memory.

TCE also causes minor to moderate irritation. As a degreaser, TCE strips the skin of its natural protective oils. With frequent exposure, skin can

be irritated, resulting in dermatitis and even burns and blistering in extreme cases. The vapor of TCE can irritate the eyes, nose, and throat. TCE can also damage the facial nerves and impair vision, smell, taste, and, in extreme cases, hearing and facial muscle control. There are reports of damage to the nerves of the arms and legs that caused loss of feeling, tingling, and even paralysis. At high levels and repeated exposures, TCE can produce severe damage. The lungs are irritated under these conditions, causing chest pain, shortness of breath, and possibly even pulmonary edema (fluid in the lungs), which can be fatal. In some cases, the heart of the victim has gone into fibrillation, which can lead to death. Liver and kidney damage has been reported, but only rarely, at very high concentrations. There is also evidence of immune deficiency disorders caused by TCE, but these are rare and the link is uncertain.

The connection of TCE to cancer and reproductive problems is also uncertain. It has been found to cause tumors in the liver, kidney, lungs, and testes in laboratory mice and rats at high dosage. Evidence of cancer in humans is more circumstantial. Studies in New Jersey and Massachusetts suggested a link between TCE in drinking water and leukemia in women and children, respectively. Another long-term study, in Michigan, Illinois, and Indiana, found no appreciable difference in incidence of cancer with environmental TCE exposure, except for a slight increase in lung cancer among older men. The study concluded that this increase was probably the result of increased smoking rather than TCE exposure. In contrast, several studies suggest that TCE in drinking water may cause birth defects in humans. One study found an increase in heart defects in babies whose mothers ingested TCE in drinking water. This study is supported by similar findings for animals in laboratory studies. Another study found an increase in a rare respiratory defect, as well as eye defects. Other birth defects attributed to TCE exposure include neural tube defects, oral cleft palates, hearing and speech impairment, and even childhood leukemia. Most of the results of the epidemiological studies yield only slight indications of a link between environmental TCE and these defects, which might be explained by other exposures that were not tested.

### REGULATIONS ON HUMAN EXPOSURE

As a result of these numerous and serious health effects from exposure to TCE, federal agencies regulate public and worker exposure. This regulation of TCE began in 1980 because it is covered under the Clean Water Act as a hazardous substance. In 1989,

the EPA set a drinking water standard for community water supplies of five parts per billion (ppb) of TCE. They also require industry to report any spill of 1,000 pounds (454 kg) or more. There is a proposal to reduce that number to 100 pounds (45.5 kg). The Occupational Safety and Health Administration (OSHA) set a national occupational exposure limit of 100 parts per million (ppm) in air for an eight-hour-day 40-hour workweek, although local jurisdictions may set their own standards. In California, for example, the limit is 25 ppm, and in Illinois it is 50 ppm. The national OSHA 15-minute maximal average is 300 ppm.

*See also* BIOREMEDIATION; CHLORINATED SOLVENTS; ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TCA.

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**temperature inversion** Normally, temperature decreases progressively with elevation above the Earth's surface. In some special cases, however, temperature may increase with elevation for a short distance above the surface before returning to the normal gradient. This special situation is a temperature inversion, and it commonly results in a period of increased to excessive air pollution. This situation has been responsible for virtually all the air pollution disasters. A radiation inversion type of temperature inversion occurs in very stable weather conditions



with no wind or precipitation. The Sun heats the Earth's surface by day; it, in turn heats the air above it. This is especially true in heat islands of cities with all of the blacktop pavement and brick, cement, and glass buildings. The heated air can extend quite high with the lack of wind. At night, the city cools, but air is such a good thermal insulator that it remains warm. Eventually, because the surface is cool, the air near the cooled surface cools to a lower temperature, thus making it denser and holding the pollutants near the ground. Topography can increase this effect when cold air flows down hills and concentrates in valleys. In either case, these radiation inversions last on the order of hours before the Sun heats the surface enough to reestablish a normal thermal gradient.

The much worse case is the subsidence inversion. This is a regular occurrence in cities that lie in valleys or basins and are prone to large high-pressure systems. One of the worst areas for this is Los Angeles, California. The Pacific high is a semipermanent atmospheric feature off the coast of California. In addition to the falling air from the high pressure, cool marine air from the Pacific Ocean significantly

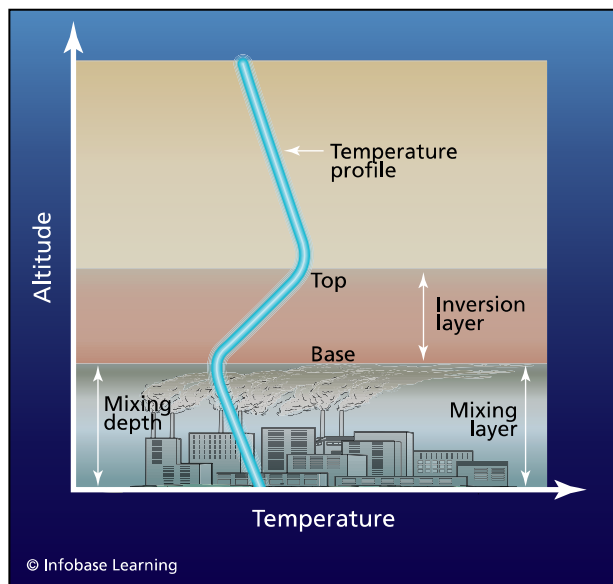
cools the air at lower elevations, causing a substantial inversion. Further, the San Gabriel Mountains to the east inhibit the drifting of the weather system out of the Los Angeles basin commonly for an extended period (days to weeks). About 80 percent of the time between June and August, Los Angeles is smoggy and in a temperature inversion. Denver, Colorado, has a similarly unfortunate mix of topography, making it extremely susceptible to smog as well.

The high pressure forces air downward into a valley or basin, which prevents the air from escaping laterally. This causes the air to stagnate in the topographic enclosure. Normally, the common air pollution generated in an area is dispersed by dilution with circulating air. There is no buildup of these pollutants, and, as a result, few health problems under normal conditions. If the air cannot circulate because of a temperature inversion, pollutants quickly build to dangerous levels. If the weather does not break, an air pollution disaster can occur.

All the major air pollution disasters involving common air pollutants resulted from major and prolonged temperature inversions. The deadliest air pol-



Early morning steam from a midwinter temperature inversion shrouds the Aerial Lift Bridge in Duluth, Minnesota, 2005. (AP Images)



**Illustrated graph of temperature versus altitude during a temperature inversion. Normally, temperature would show a steady decrease with altitude. The inversion layer shows a reverse in this trend, and consequently exhaust gas is trapped beneath it, resulting in dangerous air pollutant levels.**

lution disaster was in London, United Kingdom, in 1952. A temperature inversion sealed smoke, automobile exhaust, and lesser amounts of industrial emissions in the city and up to 12,000 people died of respiratory failure as a result. The major American air pollution disaster was also caused by a temperature inversion, in Donora, Pennsylvania, in 1948. Cliffs along a river prevented lateral air movement, and largely industrial emissions concentrated to deadly levels. The other two major disasters involved temperature inversions that helped to build up deadly levels of sulfur dioxide gas from industrial sources. The first was in the Meuse Valley, Belgium, in 1930, and the second was in Poza Rica, Mexico, in 1950. Both resulted in death and both sparked changes in regulations of pollutants.

See also AIR POLLUTION; DONORA KILLER FOG; LONDON "KILLER FOG"; MEUSE VALLEY DISASTER; PENNSYLVANIA COAL MINE FIRES; POZA RICA DISASTER; SULFUR DIOXIDE.

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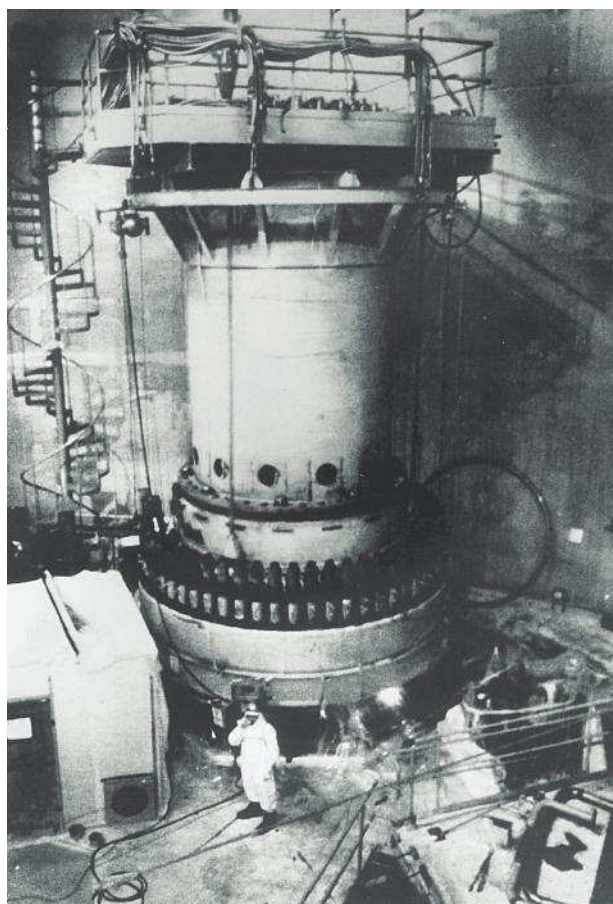
**Three Mile Island Middletown, Pennsylvania (March 28, 1979) Air Pollution** The accident at the Three Mile Island Unit 2 nuclear power plant was the most serious in United States nuclear power plant history. Even though it led to no deaths or injuries, the specter of a nuclear disaster at a commercial power plant captured the attention of the nation. Americans had long been warned of the dangers of nuclear power, and this situation had all of the signs of just such a disaster. As a result, the television and film industries picked up on the theme and "message" films, such as *The China Syndrome*, were released to critical and public acclaim and controversy. The incident and concern led to sweeping changes in emergency response planning, reactor operator training, radiation protection, and many other areas of nuclear power plant operations. It also caused the U.S. Nuclear Regulatory Commission to tighten its regulatory oversight on nuclear power plants. These changes in the nuclear power industry enhanced the safety and may prevent much more serious situations and potential disasters in the future.

#### THE REACTOR ACCIDENT

At 4:00 A.M. on March 28, 1979, Unit 2 of the Three Mile Island power plant had a malfunction in the secondary, nonnuclear section of the plant. The main cooling water pumps stopped running, preventing the steam generators from removing heat. As a result, the turbine and the reactor automatically shut down, and pressure began to increase in the primary nuclear section of the plant. The pilot-operated relief valve opened in order to prevent that pressure from becoming excessive. The valve was supposed to close when the pressure decreased to a designated level, but it did not. The signals that were meant to notify the operator that the valve was still open failed to operate. As a result, cooling water poured out of the stuck-open valve and caused the core of the reactor to overheat.

The information on the instruments of the reactor operators was confusing as more coolant flowed from the core through the pressurizer. None of them

showed the level of coolant in the core. The operators used the level in the pressurizer to determine the level of water in the core. They assumed that the core was properly covered with coolant because it was high. In addition, there was no signal showing that the pilot-operated relief valve was open. As a result, even though alarms sounded and warning lights flashed, the operators did not realize that the plant had lost coolant. Consequently, they reduced the flow of coolant through the core and made conditions worse. Without enough coolant, the nuclear fuel overheated to the point at which the long metal zirconium cladding tubes that hold the nuclear fuel pellets ruptured, and the fuel pellets began to melt. About one-half of the core melted during the early stages of the accident. Although Unit 2 suffered a severe core meltdown, the most dangerous kind of nuclear power accident, it did not proceed to a worst-case scenario. In this worst-case accident, the melting of nuclear fuel would lead to a breach of the walls of the containment building and release massive quantities of radiation to the environment.



**Damaged reactor at Three Mile Island nuclear power plant, Harrisburg, Pennsylvania, 1979** (Rolls Press/Popperfoto/Getty Images)

## RESPONSE TO THE ACCIDENT

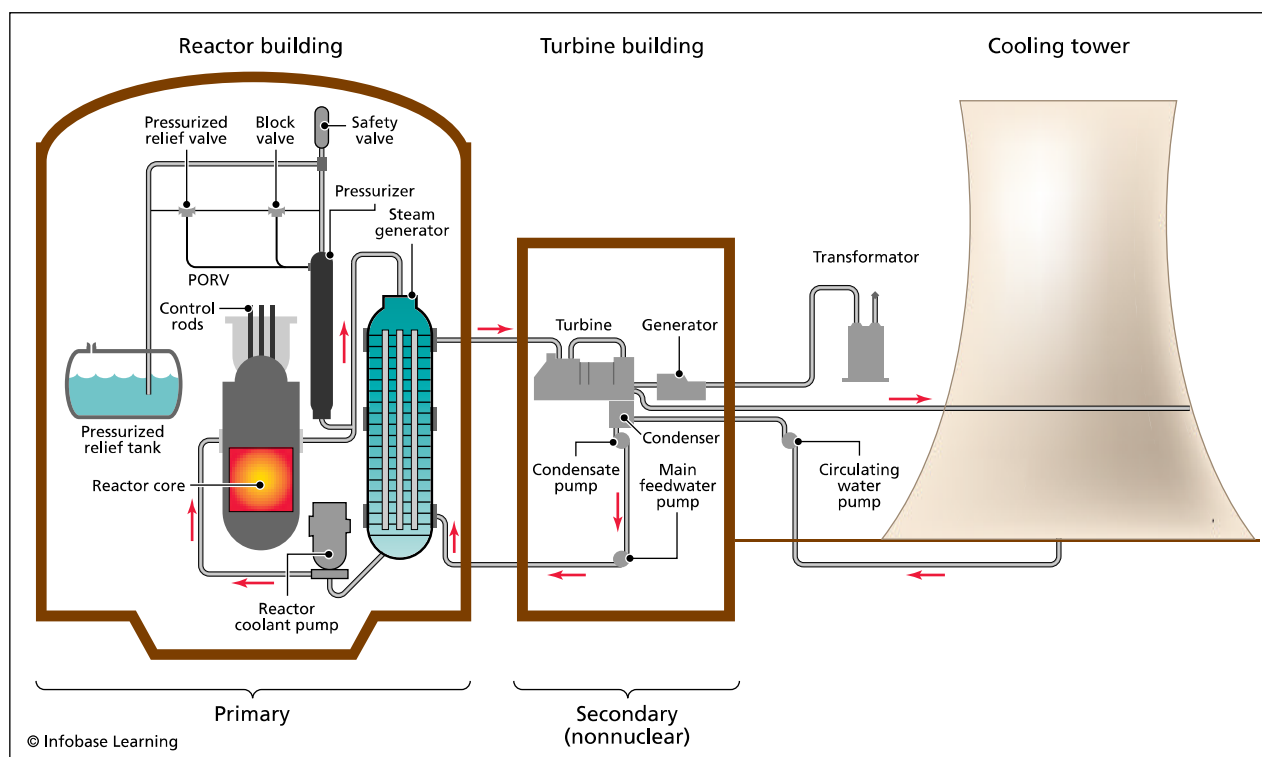
The U.S. Nuclear Regulatory Commission (NRC) regional office in King of Prussia, Pennsylvania, was notified of the accident at Three Mile Island at 7:45 A.M., three and three-quarters hours later. By 8:00 A.M., NRC Headquarters in Washington, D.C., was alerted and the Operations Center in Bethesda, Maryland, was activated. The first team of NRC inspectors was immediately dispatched to the site, and the U.S. Department of Energy and the U.S. Environmental Protection Agency (EPA) also dispatched their response teams. By midday, helicopters were sampling radioactivity in the atmosphere above the plant, and a team from the Brookhaven National Laboratory was sent to assist in radiation monitoring. By 9:15 A.M. the White House was notified, and by 11:00 A.M., all nonessential personnel were ordered to evacuate the plant.

The response teams appeared to have the plant stabilized by the evening of March 28 and whole day of March 29. On Friday, March 30, however, new concerns arose as there was a significant release of radiation from the plant auxiliary building during a pressure release on the primary system to avoid hampering the flow of coolant to the core. The growing uncertainty about the condition of the plant led Richard L. Thornburgh, the governor of Pennsylvania, to evacuate the nearby residents most vulnerable to radiation from the area. These vulnerable residents included pregnant women and preschool-age children within a five-mile radius of the plant.

Later, a large hydrogen bubble formed in the dome of the pressure vessel, the container that holds the reactor core. The fear was that the hydrogen bubble could explode and rupture the pressure vessel. If that happened, the core might fall into the containment building and cause a breach of the containment. This latest crisis ended when on Sunday, April 1, it was determined that the bubble could not burn or explode because there was no oxygen in the pressure vessel. By that time, they had succeeded in greatly reducing the size of the bubble.

## HEALTH EFFECTS OF EXPOSURE

Because this was the most serious accident that ever occurred at a U.S. commercial nuclear reactor, there were many detailed radiological studies conducted on the residents of the area by the NRC, the EPA, the Department of Health and Human Services, the Department of Energy, and the state of Pennsylvania, among others. Thousands of samples of air, water, milk, vegetation, soil, and foodstuffs were collected by numerous groups monitoring the area. Only very low levels of radionuclides could even be



**Diagram showing the components of the Three Mile Island Unit 2 nuclear reactor in which the accident occurred. Basically, the nuclear reaction in the core heats water into steam in the primary, which drives a turbine and generator in the secondary. The cooling tower prevents the reactor from overheating.**

possibly attributed to releases from the accident. Estimates are that the average dose to about 2 million people in the area was only about 1 millirem, about one-sixth the exposure from a full set of chest X-rays. Comprehensive investigations by several well-respected organizations concluded that in spite of the serious damage to the reactor, most of the radiation was contained and the actual release had negligible effects on the physical health of individuals or the environment.

### REGULATORY IMPACT OF THE ACCIDENT

The accident at Three Mile Island was caused by personnel error, design deficiencies, and component failures. It permanently changed the nuclear industry. Public fear and distrust of nuclear energy increased, the NRC's regulations became more stringent and oversight became broader, and the management of plants was more carefully scrutinized. The identification of problems that led to the accident has led to permanent and sweeping changes at the NRC that have reduced the risk to public health and safety.

The major changes include the upgrading and strengthening of plant design and equipment requirements such as fire protection, piping systems, auxiliary feedwater systems, containment build-

ing isolation, reliability of individual components including pressure relief valves and electrical circuit breakers, and ability of plants to shut down automatically. Other changes include the identification of human performance as a critical part of plant safety, revision of operator training and staffing requirements, improvement of instrumentation and controls for operating the plant, and establishment of fitness-for-duty programs for plant workers to guard against alcohol and drug abuse. There was an enhancement of the emergency preparedness system to include immediate notification of NRC for plant events and an operations center that is continuously staffed. Drills and response plans must be tested by licensees several times per year, and state and local agencies participate in drills with the Federal Emergency Management Agency.

Other changes include the issuing of annual public reports on the plants. There was enhancement of the inspection and the management systems including on-site offices. Expansion of performance and safety inspections, as well as the strengthening and reorganization of enforcement as a separate office within the NRC, were added. The Institute of Nuclear Power Operations (INPO) was established as the industry's own "policing" group. The Nuclear Energy Institute was formed to provide a unified approach to com-



mon nuclear regulatory issues and to interact with the NRC and other government agencies. In addition, the NRC's international activities were expanded to share enhanced knowledge of nuclear safety with other countries in a number of areas.

### CURRENT STATUS

The Three Mile Island reactor number 2 is now permanently shut down and defueled. The reactor coolant system is drained; the radioactive water is decontaminated and evaporated; the radioactive waste was shipped off-site to a disposal site; the reactor fuel and core debris have been shipped off-site to a Department of Energy facility; and the remainder of the site is being constantly monitored. It will be kept in the facility in long-term, monitored storage until the operating license for the Three Mile Island reactor number 1 plant expires, at which time both plants will be decommissioned.

After the Chernobyl disaster a decade later, Three Mile Island was largely forgotten because its effects and seriousness were dwarfed in comparison.

See also AIR POLLUTION; CHERNOBYL NUCLEAR DISASTER; RADIOACTIVE WASTE.

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**tides** Tides are the periodic rise and fall of any liquids on or below the surface of the Earth. They are caused by response of the liquids to the gravity of the Moon and or Sun. Ocean tides are the most important and have the greatest influence on the environment. There are typically two high tides and two low tides per day separated by six hours each. High tides occur when the Moon is directly overhead or over the direct opposite side of the Earth. Low

tides occur when the Moon is one-quarter or three-quarters of the way around the Earth from the point of vantage. Therefore, if there is a high tide at 6 A.M., there will be a low tide at noon, another high tide at 6 P.M., and another low tide at midnight.

### TIDAL REACH

The tidal reach, or height, in an area at high tide and low tide varies throughout the month. This variability is caused by gravity imposed by the Sun. If the Sun, Moon, and Earth align (with the Sun on either side), high tides will be at their highest and low tides will be at their lowest. The reason for the extremes is that the gravities of the Sun and Moon are added. This situation is referred to as spring tide and typically corresponds to a full Moon. If the alignment of the Sun and Earth is positioned at a right angle to the alignment of the Moon and Earth, it is neap tide. Neap tides result in lower high tides and higher low tides than normal. Neap tides typically occur at half moon situations.

The main controlling factor in the tidal reach or height at a particular location is the shape of the basin. Smaller, shallower basins produce small tides and may even have only one tide per day. Lakes have small tidal reach. Larger, deeper basins generally produce larger tides. The shape of the basin and especially the margins also plays a big role in tidal reach. On the New Jersey shore, the typical tides are about six feet (1.85 m) high, whereas in the Bay of Fundy, Nova Scotia, Canada, the tides are an amazing 32 feet (9.85 m) high, yet both face the Atlantic Ocean. The difference is that the ocean floor is shallow and flat off the New Jersey shore but very steep and deep off Nova Scotia. There is more water available there to make larger tides.

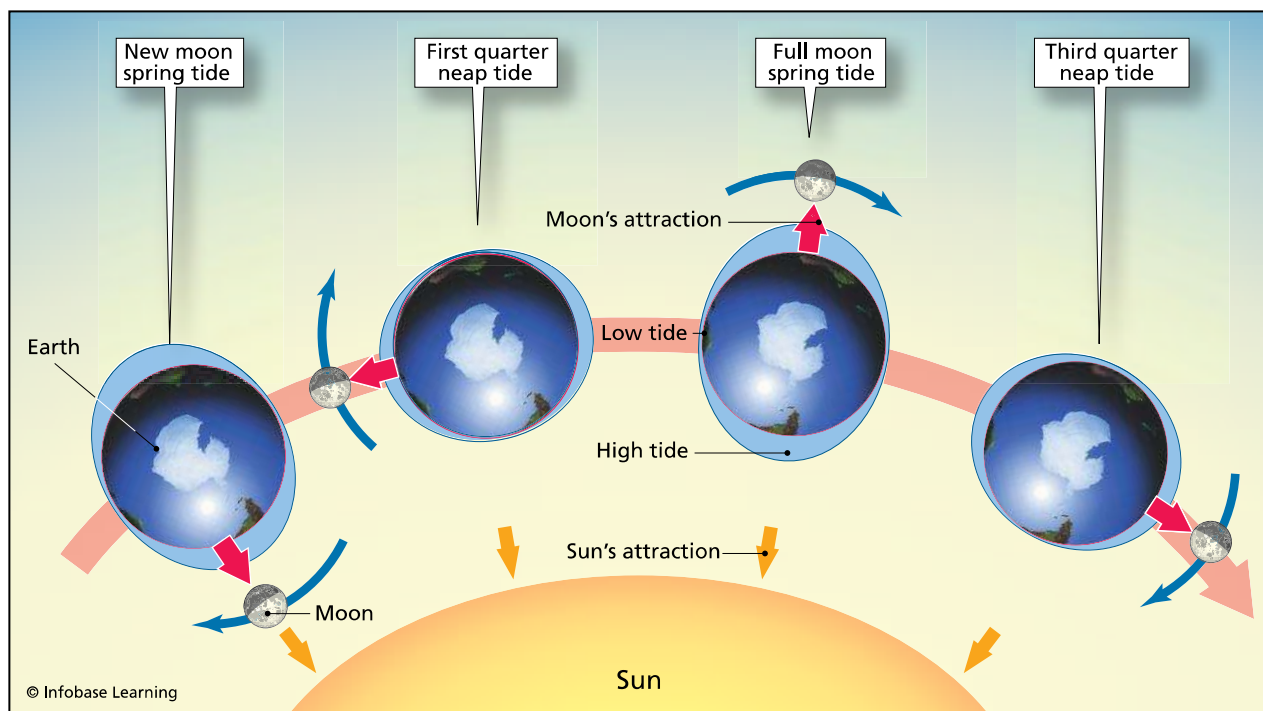
### TIDES AND POLLUTION

Tides can have an influence on pollution in several ways. The primary effect of tides is on oil or chemical spills in the ocean. Tides can drive the oil and other pollutants up rivers and high onto beaches and shorelines, where it affects the terrestrial plants and animals. Waste disposed through ocean dumping can be pushed back onto beaches. High tides during storms can help to undermine and remove stored chemicals and other pollutants into the ocean, causing dangerous conditions.

See also BEACHES; CONTINENTAL SHELF; WAVES.

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The gravitational attraction of the Moon and, to a lesser extent, the Sun generates tides. The tidal range is largest (spring tides) when the Moon and Sun are in alignment relative to Earth. The tidal range is smallest (neap tides) when the Moon and Sun are at right angles.

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### Times Beach Superfund site Times Beach, Missouri (1979–1997) Soil Pollution

Times Beach, Missouri, was a small (480-acre, or 194-ha) suburban community about 20 miles (32 km) west of Saint Louis. Built on the floodplain of the Meramec River, in the early 1970s, it had a population of approximately 1,200 people. Times Beach began as a 1930s vacation river town and had slowly evolved into a lower-middle-class community.

#### POLLUTION OF THE SITE

Every summer between 1972 and 1976, the city of Times Beach along with nearby businesses, farmers, and stables hired a local waste hauler to spray oil on unpaved roads for dust control. The cost of this spraying was \$0.06 per gallon (\$0.02 per L) of oil

applied. The waste hauler, Russell D. Bliss, picked up used or spent/off-spec oil from automobile service stations, heating oil distributors, machine shops, and other similar places, either free as a waste removal service or by paying a few pennies per gallon (3.8 L) for it. He then sprayed the oil on unpaved roads. The state of Missouri had licensed him as a waste hauler, and in the 1970s oiling was a common method of dust control.

Wishing to expand his small business, Mr. Bliss approached and was hired by Northeast Pharmaceutical and Chemical Company (NEPACCO) of Verona, Missouri, to dispose of spent chemicals from its agricultural chemical (a hexachlorophene-based pesticide) manufacturing operation. Instead, Mr. Bliss mixed these chemicals them with the used oil that he sprayed on the roads, horse tracks, and farms around the Times Beach area and some 26 other locations. Approximately 4,000–5,000 gallons (15,142–18,927 L) of oil containing 300 parts per million (ppm) dioxin was dispersed in this manner.

Dioxin, also known as 2,3,7,8-tetrachlorodibenzo-para-dioxin or TCDD, is the active ingredient in some types of pesticides and herbicides. During the 1970s, this compound was considered the most lethal substance ever created, 150,000 times more toxic than cyanide and 670,000 times as lethal as strychnine. It was the main component of Agent

Orange, a defoliant widely used during the Vietnam War. Subsequent studies indicate that dioxin compounds are no more dangerous than similar types of industrial and agricultural chemicals.

The first indications of potential environmental problems in Times Beach began in 1971. Local stable owners reported a sudden increase in the deaths of otherwise healthy horses. They found a common link: More than 60 horses had died in stables whose tracks, paddocks, and access roads had been oiled by Bliss. When confronted by the owners, Bliss assured them that the material he had used was simply motor oil and had nothing to do with the death of the animals. The stable owners were not convinced and contacted the Centers for Disease Prevention and Control (CDC). In late 1979, after an extensive investigation by CDC in addition to other state and federal agencies, a NEPACCO employee admitted that the company had been selling its waste dioxin to Bliss.

Concerned about the potential public health implications, the U.S. Environmental Protection Agency (EPA) began an investigation of Bliss's activities. In November 1982, the EPA notified Times Beach residents that the city might have been among the sites sprayed by Bliss with waste oil contaminated with dioxin. The EPA began collecting soil samples in Times Beach, even though the roads had since been paved and oiling was no longer needed to control the dust. One sample collected in early December 1982 contained dioxin levels almost 300 times greater than the concentration considered to be safe. As the sampling data were being reviewed and analyzed, heavy rains caused the worst flood in Times Beach history. The Meramec River crested 20 feet (6.2 m) above flood stage, and the flood spread dioxin-contaminated soil and mud everywhere. By the time the water started to subside, the EPA had confirmed the presence of dangerous levels of dioxin, and, on December 23, 1982, Times Beach residents received the following Christmas message from EPA officials:

If you are in town it is advisable for you to leave and if you are out of town, do not go back.

Sampling results confirmed the presence of dioxin at levels up to 100 parts per billion (ppb). The safe level was considered to be 1 ppb. Panic spread through the community and surrounding area, with many illnesses, miscarriages, and animal deaths attributed, correctly or not, to the dioxin.

The state police and national guard blockaded roads and refused to let anyone in or out. Dioxin, which is designed to cling tightly to soil particles, had been spread throughout the town by Meramec

River floodwaters. The now-contaminated soil covered the entire 0.8-square-mile (2.1-km<sup>2</sup>) area of Times Beach, and public health officials were concerned that if residents fled, they would track the contamination to other areas of Missouri.

### BUYOUT OF RESIDENTS

As the plight of the Times Beach residents attracted national attention, the federal government stepped in slowly to offer relief. In 1983, the EPA administrator, Anne Burford, announced a \$33 million buyout of the entire town of 437 permanent homes, 364 mobile homes, and 45 businesses. Residents rejected this compensation offer and a subsequent one by EPA because they were below market value. It was several years before the buyout was completed, but finally, after intervention by Missouri's congressional delegation, the EPA offered acceptable compensation. The stigma of having lived in Times Beach, however, was not as easy to overcome. Evacuees from Times Beach often were shunned by their new neighbors, who were afraid that the effects of dioxin exposure might be contagious.

Russell Bliss denied any wrongdoing, claiming that NEPACCO had never informed him that the material was hazardous. This conflicted with testimony by NEPACCO employees that Bliss's drivers were issued protective clothing and warned of the dangerous nature of the waste during pickups. Bliss's waste-hauling license was not renewed, and, despite his questionable disposal practices, he was never indicted or convicted of any crime. In 1983, Bliss and NEPACCO were sued by 183 of the town residents for \$1.8 billion in damages. NEPACCO declared bankruptcy the following year. Its insurers settled the lawsuit for \$19 million, with each plaintiff receiving, on average, slightly more than \$100,000, before attorney's fees.

### THE CLEANUP

The cleanup implemented by the EPA was unique and has never been repeated since on such a massive scale. Between March 1996 and June 1997, more than 10 years after the contamination was discovered, approximately 240,000 tons (217,724 metric tons) of soil and every building, structure, and part of the town (except for one small house) were burned in a high-temperature incinerator constructed near the former municipality. This debris included essentially all of Times Beach and most of the ground it rested on.

After collection and processing by shredding, grinding, and adding lime to reduce moisture levels,



the waste material was incinerated in a 75-foot- (23-m-) long rotary kiln lined with a nine-inch- (22.9-cm-) thick layer of high-temperature, acid-resistant insulating refractory. Processing about 40 tons (36.3 metric tons) of waste per hour, the kiln rotated at one rotation per minute (rpm) and reached a firing temperature of 1,250°F (677°C). At these temperatures, the chemical bonds holding the organic compounds together were destroyed, and the material was broken down to its basic elemental components (carbon, hydrogen, chlorine, etc.). Just to make sure all the dioxin was thoroughly destroyed, exhaust gases from the kiln were routed to a secondary combustion chamber that operated at an even higher temperature of 1,750°F (954°C).

The incinerator also was equipped with an emergency backup system. If the primary and secondary burners failed, gases from the kiln would be diverted to a propane-fired 1,800°F (982°C) backup furnace until the system could be shut down, the wastes secured, and the problem repaired. The permit for the burning of the Times Beach waste required a dioxin removal efficiency of 99.999 percent, which this system was able to achieve, and no public health effects were reported during its opera-

tion or after the incinerator was decommissioned and dismantled.

### THE AFTERMATH

The ash and other noncombusted residues were buried and covered with clean fill, and the area was redeveloped as Route 66 State Park. Times Beach is now one of the most visited tourist attractions in Missouri. Only one building from the town still stands, an old roadhouse that had been the EPA's headquarters during the cleanup but now serves as the park's visitor center. The cost of remediation to the federal government was approximately \$140 million, \$10 million of which was reimbursed by Syntex, NEPACCO's parent company.

Illnesses related to toxic exposures to dioxin affected 10 people. Most severely affected was a six-year-old who suffered kidney and bladder damage that required hospitalization and surgery. Less severely affected persons developed diarrhea, headaches, nausea, and skin lesions. Some 63 horses, six dogs, 12 cats, and 70 chickens died as a result of dioxin poisoning, along with uncountable rodents and insects. Later research on the toxicity of dioxin



Loading of dioxin-contaminated debris at Times Beach, Missouri, 1983 (© Bettmann/CORBIS)



has led to controversy as to whether the EPA's decision to evacuate and incinerate Times Beach was appropriate.

*See also* DIOXIN; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; PESTICIDES; STREAM; SUPERFUND SITES; WATER POLLUTION.

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#### **Tittabawassee River contamination Midland, Michigan (2000–present) Soil and Sediment Pollution**

The Michigan Basin is a bowl-shaped structure of sedimentary rock located near the center of the Lower Peninsula of Michigan. The basin was actively subsiding during sedimentation as recorded by Early Paleozoic (500 to 400 million year old) rocks more than 15,000 feet (4.6 km) thick in the center, but 4,000 feet (1.2 km) thick around the margins. Overlying units show the same thickening toward the center. This active subsidence in an enclosed area of high temperatures also resulted in the deposition of a significant thickness of salt, gypsum, and other evaporate rocks for which the area has become renowned.

As Michigan's Lower Peninsula was explored and settled, first by trappers, then for its timber and later rich farmland, early pioneers discovered outcrops of salt and related deposits. Sometimes, these early explorers found mastodon and saber-tooth tiger bones, among others, near these deposits, the remains of prehistoric animals drawn there by the salt. Commercial developers exploited these salt deposits, and for many years in the early 1900s, Michigan was one of the major salt-producing states in the country.

#### BACKGROUND

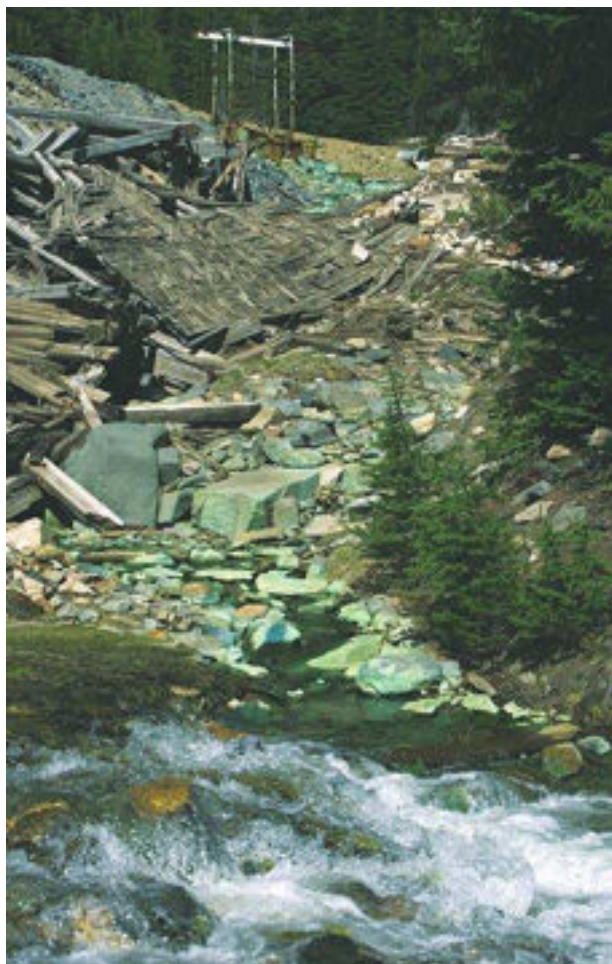
A chemist named Herbert Henry Dow was also drawn to these deposits of salt and the brine-rich groundwater associated with them. In 1879, Dow began a company in the small town of Midland, Michigan, to test his new procedure for the extraction of bromine from the natural brines that could be pumped to the surface in parts of Midland, Manistee, Muskegon, Wayne, and Saint Clair Counties. Bromine was an important chemical at the time and was often found associated with salt deposits. It was used in fumigants, pesticides, dyes, and water purification and in film for the rapidly expanding photography industry. Bromine is a heavy, volatile, mobile, and very dangerous reddish brown liquid. Similar to chlorine and often used as a bleaching compound, it has a strong unpleasant odor, and bromine vapors can irritate the eyes and throat.

The Dow Corporation started to grow quickly, at first selling potassium bromide and bleach and eventually diversifying to become one of the major providers of plastics, chemicals, and agricultural products. Today, it is the world's second largest chemical manufacturer with operations in more than 150 countries and more than 45,000 employees. In 2009, Dow's annual sales totaled approximately \$50 billion. Despite its rise in commercial importance, Dow never abandoned its Michigan roots. The company still is headquartered in Midland and operates a 1,900-acre (769-ha) facility on the southern edge of town. Products produced by Dow at Midland include Saran Wrap, Styrofoam, Mustard Gas, Agent Orange, and various agricultural pesticides.

#### POLLUTION OF THE SITE

To manage its liquid wastewaters, in the early 1900s, Dow Chemical constructed a series of lagoons, or ponds, on a 600-acre (243-ha) parcel of its Midland plant. Wastewater was discharged into these ponds, solids allowed to settle, and decanted liquid discharged into the adjacent Tittabawassee River. Today, liquid wastes generated from production operations are processed through Dow's advanced wastewater treatment plant before being released into the environment.

The Tittabawassee River flows southward through the Lower Peninsula in the east-central portion of the Michigan Basin and eventually joins the Shiawassee River to form the Saginaw River near Midland, just downstream of the Dow plant. The Saginaw River then enters Saginaw Bay, which leads into Lake Huron. During high-flow periods, after heavy rains, for example, Dow intentionally released excess liquids from the waste ponds. Even though



**Discharges of dioxin-contaminated wastewater from this chemical plant significantly impact sediment quality in the adjacent Tittabawassee River, Saginaw, Michigan, 2005. (Junebug Clark/Photo Researchers, Inc.)**

this was a standard waste management practice at the time, these and other types of wastewater discharges had a significant impact on the environment. In particular, a flood in 1986 overwhelmed the Dow treatment plant, submerged portions of the manufacturing area, overflowed containment dikes, and washed untreated chemical wastes and contaminated soil into the Tittabawassee River. When it finally subsided, a 20-mile (32-km) stretch of river downstream of Dow's Midland facility was contaminated with dioxins and furans.

Dioxins and furans are a class of related chemicals that are more correctly known as polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans and contain 210 individual compounds (75 dioxins and 135 furans). Dioxins and furans are not manufactured intentionally; they are by-products of several commercial chemical processes. Scientific studies show that short-term exposure to elevated

levels of dioxins and furans results in a wide variety of health problems such as skin disorders (chlor-acne), liver damage, immune system damage, and the development of certain types of cancers. Almost all environmental and public health agencies worldwide have established very low exposure guidelines for these substances, especially for 2,3,7,8-tetrachloro-p-dibenzo-dioxin (2,3,7,8-TCDD), which generally is acknowledged to be the most toxic of the dioxins and furans. Once in the environment, dioxins and furans are very resistant to biodegradation and move up the food web, becoming concentrated in body fat. The vast majority of an individual's exposure to dioxins and furans is through meat, milk products, and fish.

Dioxins and furans were discovered in the channel and floodplain sediments of the Tittabawassee River in 2000 during an ecological sampling program being conducted downstream of the Dow plant in Midland by General Motors Corporation. During a wetland restoration project, General Motors sampled and analyzed sediments in a farm field in the Tittabawassee River floodplain adjacent to one of their manufacturing facilities and discovered dioxins and furans at concentrations up to 2,200 parts per thousand (ppt), about 25 times higher than allowed by state regulations. General Motors promptly notified the Michigan Department of Environmental Quality (MIDEQ), which initiated an investigation. Early studies by MIDEQ found that dioxin and furan levels in sediment samples increased nearer to the Dow plant but decreased dramatically upstream of the facility to less than 10 ppt. Soil samples taken from outside the floodplain contained concentrations of dioxins and furans at background levels of about 6 ppt.

Levels of dioxin downstream of the Dow plant ranged from 39 ppt to more than 7,200 ppt in channel and floodplain sediments. Michigan's current residential cleanup standard for dioxin is 90 ppt, whereas the federal Agency for Toxic Substances and Disease Registry (ATSDR) has an action level of 1,000 ppt (or one part per million [ppm]). Other states have different cleanup criteria for dioxin: in Oregon, Washington, West Virginia, Massachusetts, and Florida, less than 10 ppt; in Iowa and Arizona, 14 ppt and 38 ppt, respectively; in Pennsylvania, 120 ppt; and in Minnesota, 200 ppt.

### THE CLEANUP

In compliance with Michigan law, which requires all who release a hazardous substance onto their own or another's property to take corrective action, Dow is implementing a variety of remedial actions to address the dioxins and furans from its facility in Midland. Dow identified and mapped areas where

dioxin is present at levels above 90 ppt. These maps play a critical role in the development and implementation of a comprehensive long-term plan to address the dioxin-contaminated sediments and soils in the channels and floodplains of the Tittabawassee River.

Dow Chemical is also working cooperatively with MIDEQ and local health officials to educate residents on ways to reduce exposure to dioxin. For example, animals that graze on plants grown in dioxin- or furan-contaminated soil ingest these compounds and retain them. The dioxins and furans can then be passed on to people who consume the meat, milk, or eggs of these animals. Health advisories have been issued for eating fish from the Tittabawassee River downstream of Midland. Bottom feeders that tend to feed in sediment such as carp, catfish, or white bass should not be eaten, and children and pregnant women should not eat any fish from the river more than once per month. Similarly, Midland County health officials are urging residents to avoid eating animals that have grazed in floodplain sediments downstream of the Dow plant and have advised landowners not to conduct activities that may disturb floodplain sediments such as dredging or regrading.

Finally, Dow has implemented short-term remedial measures to reduce the risks to children or those who have impaired immune systems because they have the greatest potential for sensitivity to dioxin. In those cases, contaminated soil has been excavated from backyards. This phased approach to cleanup has been slow, and some government officials, community leaders, and local environmental activists are unhappy with the delays. In 2005, some 2,000 property owners within the floodplain of the Tittabawassee River filed a class action suit against Dow for diminution of property values, claiming that their land is now essentially worthless because of the dioxin contamination. Dow successfully fought to prevent the class action from being certified, claiming that the plaintiffs' cases were different, and should be tried on a case-by-case basis. The landowners are now appealing that decision, and the suit is working its way through the court system as both Dow and MIDEQ continue to search for a way to address this area of widespread contamination.

See also AQUIFER; DIOXIN; FURAN; PESTICIDES; STREAMS; WATER POLLUTION.

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**tobacco smoke** Tobacco is, by far, the deadliest environmental hazard in the world, directly causing more than 420,000 deaths (one in five) in the United States per year alone. It has been called "the leading preventable cause of disease and death in the United States" by the surgeon general. There are more tobacco-related deaths per year than deaths from human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), illegal drug use, alcohol use, motor vehicle accidents, suicides, and murders combined. There are three sources of tobacco exposure, smoking, smokeless (chewing and snuff), and environmental tobacco smoke. By far, the most deadly is smoking, but it is more a health than an environmental issue. There will be a short review of effects directly related to smoking and smokeless tobacco, but the main point of this discussion is environmental tobacco smoke, or secondhand smoke. In recent years, the adverse health effects of secondhand smoke have raised as much concern as direct smoking. Many states and municipalities have passed laws regulating exposure in most public buildings, even in businesses traditionally known for smoking, from restaurants to bars and night clubs. The public outcry against smoking has reduced its use and consequently public exposure, and this trend is likely to continue into the future.

#### HISTORY, USE, AND PRODUCTION

Tobacco is an American product. There is Mayan art depicting its use as much as 1,500 years ago.





**Tobacco smoke contributes to indoor air pollution and poses serious health risks to nonsmokers, especially children.**  
(Manuel Martinez; used under license from Shutterstock, Inc.)

European explorers in the 1500s were the first non-native Americans to use tobacco. Its use spread from the Americas to Europe in the middle of the 16th century, and from there, it spread throughout the world. The most popular form of tobacco use was as snuff, prior to the 1800s, in both Europe and the United States. Chewing tobacco use increased until it peaked in 1900 at 4.1 pounds (1.9 kg) per American male older than the age of 15. Cigars and pipe tobacco were the most popular forms of smoking in the 18th and 19th centuries. They were rapidly replaced by cigarettes after about 1910. The annual per capita use of cigarettes in 1900 was about 54 for Americans. By 1963, it had reached 4,345, when it peaked. The consumption of cigarettes steadily declined thereafter, largely through education of the general public about the emerging research that showed how deadly tobacco is. By 2002, annual per capita consumption of cigarettes had dropped to fewer than 2,000. In terms of total cigarettes, the consumption was 2.5 billion in 1900, 640 billion in 1981, and 420 billion in 2002. There was a small resultant shift toward chewing tobacco as consumption of cigarettes declined. In 1962, the consumption was 0.5 pound (0.23 kg) per year but

increased to 1.05 pounds (0.48 kg) per year by 1966 and 1.34 pounds (0.61 kg) per year by 1982 before declining to 0.8 pound (0.36 kg) per year, where it has remained, by 1991.

Tobacco has been produced as a major economic crop in the United States since the 1600s. Between 1987 and 1997, the tobacco harvest in the United States was approximately 1.19–1.79 billion pounds (540–812 million kg) per year. Imports totaled 11 billion cigarettes in 2000 but more than 20 billion by 2002. Exports of tobacco greatly outnumber imports with 148 billion exported in 2000 and 127 billion in 2002.

### TYPES AND COMPONENTS OF TOBACCO SMOKE

Tobacco smoke of all kinds is a complex mixture of a vast array of chemical compounds. To date, approximately 4,000 chemical compounds have been identified of the estimated 100,000 total in tobacco smoke. These 4,000, however, represent 95 percent of the total mass. Included in these 4,000 compounds are more than 50 that are known carcinogens and up to 400 that are toxic. These numbers depend upon the fertilizer used in tobacco growth, the chemicals used in processing, pH, and the method of smoking, among other things. One source of the hazardous substances is the burning or partial burning of the tobacco and paper. The other main source is the tobacco itself, which has been used in phytoremediation because of its ability to uptake dangerous substances during growth. A much less important source are the up to 600 additives that are included in tobacco during processing. Among the hazardous compounds in tobacco smoke are tar, arsenic, lead, cadmium, nickel, carbon monoxide, carbon dioxide, nitrogen oxides, hydrogen cyanide, benzene, ethylbenzene, vinyl chloride, dioxin, polycyclic aromatic hydrocarbons (PAHs) including benzopyrene, volatile and nonvolatile aldehydes and ketones, hydrazine, quinones, butadiene, radioactive polonium, ammonia, N- and other nitrosamines, phenols, alcohol, carboxylic acid, formaldehyde, nicotine, sulfur dioxide, and various pesticides and fertilizers. With an ingredient list like this, it is no wonder that tobacco smoke is dangerous.

There are two basic modes of smoke exposure, direct inhalation and environmental tobacco smoke, which is also known as passive smoking and secondhand smoke. Of these, there are two kinds of smoke, mainstream, which is drawn through the tobacco column and directly into the respiratory system, and sidestream, which is produced by smoldering. This difference is not just in delivery method. Mainstream smoke is produced at higher tempera-



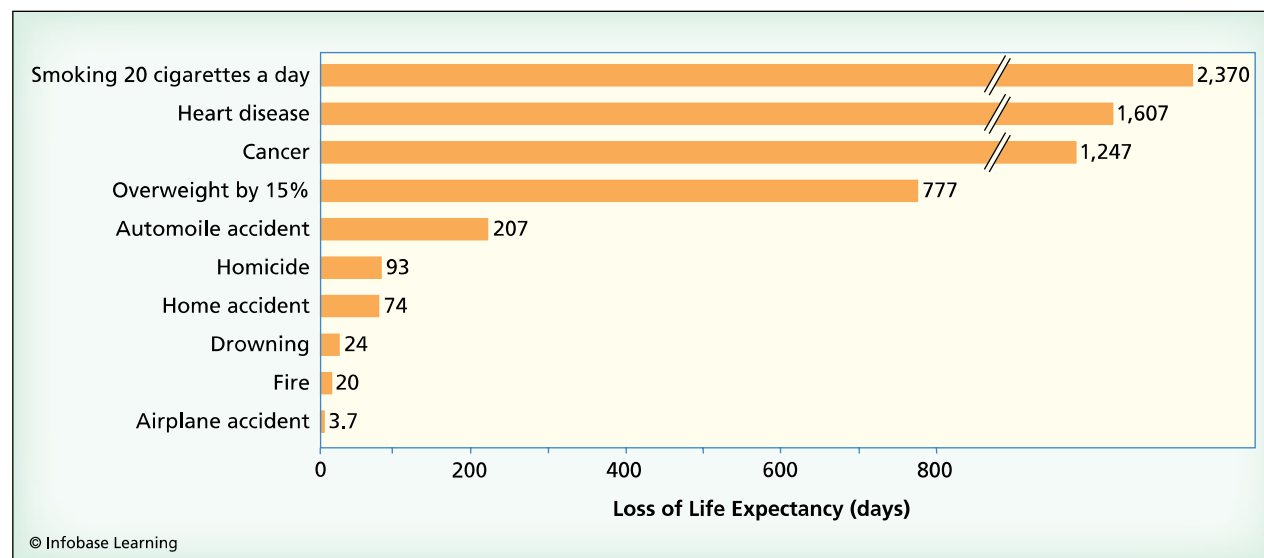
tures (1,650°F [900°C]) and under pressure flow at high oxygen conditions. It is primarily composed of nitrogen oxides and other compounds (58 percent), carbon dioxide (13 percent), oxygen (12 percent), carbon monoxide (3.5 percent), hydrogen (0.5 percent), particulate matter (8 percent), and all other elements and compounds (5 percent). Sidestream smoke is produced at lower temperatures (1,022°F [600°C]) with no flow and under oxygen-deficient conditions. Sidestream smoke results in incomplete burning of tobacco, which produces carbon monoxide as well as 40–170 times the ammonia content of mainstream smoke, four to 10 times the content of nitrogen oxides, 10 times the benzene content, six to 100 times the N- and other nitrosamines, and 30 times the aniline. The higher flow also reduces the size of particulate from 0.1 to 1 micrometer for sidestream smoke to 0.01–0.1 micrometer for mainstream smoke.

### HEALTH EFFECTS FROM EXPOSURE

There are numerous devastatingly adverse health effects from exposure to tobacco smoke and its by-products. In short, humans were not designed to inhale burned and partially burned substances for any length of time. Except for nicotine poisoning for very high doses, most effects of exposure to tobacco smoke are minor and in the form of irritation of the eyes and upper respiratory system. It is the long-term effects from chronic exposure that are particularly devastating and fall into categories of cancer, repro-

ductive problems, pulmonary disease, respiratory disease, and miscellaneous effects. The EPA, World Health Organization, and International Agency for Research on Cancer all consider both direct and secondhand smoke known human carcinogens. Cigarette smoking is responsible for 87 percent of all lung cancer deaths and 30 percent of all cancer deaths in the United States. Lung cancer is the leading cause of death of all cancers at about 119,920 per year, and smoking increases the chance of contracting it by 22 times for men and 12 times for women. In addition to lung cancer, smoking has been shown to increase the likelihood of cancers of the larynx, oral cavity, nasal cavity, sinuses, pharynx, esophagus, urinary bladder, renal pelvis, kidneys, pancreas, uterine cervix, and stomach, as well as increasing the incidence of acute myeloid leukemia. Total deaths per year from these cancers are about 31,402. These epidemiological findings for humans are supported by studies on laboratory animals. Laboratory studies also show that tobacco smoke causes genetic mutations in most cell types, especially as the result of exposure to N-nitrosamines.

Damage to the pulmonary system from tobacco smoke and especially cigarette smoke is also a major health threat. Atherosclerosis is the buildup of fat on the artery walls, is greatly increased by smoking, and is one of the major contributors to the high number of deaths. The risk of dying from the pulmonary effects is three times as high in smokers (about 30 percent of those in the United States) and is estimated at 134,235 per year. The artery dam-



**Histogram showing the loss of life expectancy for several life-threatening hazards. Smoking one pack of cigarettes daily is by far the most devastating of all hazards, on average reducing lifespan by 2,370 days, or 6.5 years, whereas smoking more than one pack daily reduces it proportionally more.**

age results in coronary heart disease, which leads to heart attacks. Smoking also increases the likelihood of recurrent coronary heart disease after bypass surgery. It reduces the amount of high-density lipoprotein (HDL), or good, cholesterol in the blood system and generally increases blood pressure. These further the likelihood of heart attack as well as blood clots, stroke, peripheral arterial disease (incidence increased 10-fold), and abdominal aortic aneurysm. Oral contraceptives work synergistically with smoking to promote strokes, which are more likely in women, in general, thus exacerbating an already dangerous situation. Smoking-induced strokes are twice as common as those in nonsmokers and kill an average of 23,281 people per year. The greatest killer from secondhand smoke is coronary heart disease by far.

Tobacco smoke also causes a variety of other diseases including bronchitis and emphysema, which are increased 10-fold and kill an average of 14,865 people per year; asthma and chronic airway obstruction, which kill 48,982 people per year; pneumonia resulting in about 19,173 deaths per year; burn deaths at 1,362 deaths per year; damaged immune system, reduced bone density, and cataracts. Smoking also increases infertility and may increase the likelihood of preterm delivery, stillbirths, low birth weight, and sudden infant death syndrome (SIDS) if the mother smokes.

Nicotine is the highly addictive drug in tobacco smoke that keeps people smoking. It is considered to be on the same level of addictiveness as heroin and cocaine and has similar effects on the brain. Nicotine acts synergistically with those drugs to keep hard-core addicts using. The rate of cigarette smoking among drug addicts is much higher than among the general public, and nicotine is considered a “gateway drug” for these and other hard-core drugs. In small doses, nicotine acts as a stimulant to the brain, but in large doses, it is a depressant that disrupts nerve transmission. It is for this reason that smoking may cause depression. To be fair, however, it is suggested that this interference may also reduce the risk of Parkinson’s disease, ulcerative colitis, Kaposi’s sarcoma, and Alzheimer’s disease and relieve the symptoms of Tourette syndrome. At high dosage, nicotine is a deadly poison that damages the heart and blood vessels as well as altering hormone levels. At high exposures, it can be fatal.

A 50-year study on smoking effects on male physicians in the United Kingdom shows that the real culprits in the dangers of tobacco smoke are cigarettes. The study showed that on average, lifetime smokers lose 10 years of life expectancy. A smoker who quits by the age of 30 suffers no long-term

effects, but by age 60, he or she has lost 7 of the 10 years. Even more important, smokers born in the late 19th century, when cigarettes were rare, had a 12 percent death rate versus a 10 percent death rate for nonsmokers. In contrast, death rates for smokers radically increased when cigarettes became popular in the 1920s. The death rate in the 1990s was 33 percent for lifetime smokers versus 7 percent for nonsmokers.

Environmental tobacco smoke (ETS) is one-tenth as deadly as direct smoking, but even at that level, it kills at least 38,000 people per year, making it the most dangerous documented environmental substance to humans. ETS produces many of the same health effects as direct smoking but in lower and different proportions. The most prevalent adverse health effect from ETS is ischemic heart disease. Its incidence is doubled among people who are regularly exposed to ETS, and it kills an estimated 35,000 people per year. It is also estimated to be responsible for 3,000 lung cancer deaths per year. Children are exposed to ETS if their parents smoke, a very dangerous condition. It may be responsible for as many as 300,000 lower respiratory tract infections per year in children below the age of 18 months. In a new epidemiological study, ETS has been shown to increase the incidence of cancer in the nasal sinus, but the rate and additional deaths are unknown. Smoke condensate, the yellow stain on walls and other areas, has been shown to cause skin tumors in mice, adding another potential problem. The health effects of ETS may be increased as time goes on as it is much more recently designated as carcinogenic and less studied.

### HUMAN EXPOSURE TO SMOKE

For direct smoke, only the smoker is affected, but for ETS, many people are affected. ETS is largely an indoor air pollutant, in too low quantity and dispersing too quickly to be of danger as an atmospheric air pollutant. The Centers for Disease Control and Prevention in their third National Health and Nutrition Examination Survey conducted from 1988 to 1991 estimated that 90 percent of the U.S. population of four years or older had detectable levels of a marker chemical, cotinine, produced by ETS in their blood. One positive sign is that the average level of cotinine was found to be reduced fourfold between 1991 and 1999. In 1991, some 43 percent of children between the ages of two months and 11 years lived in a home with at least one smoker. Even by 2001, approximately 9 million to 12 million American children six years old or younger were exposed to tobacco smoke in their

homes. Before restrictions were in place, certain businesses had higher exposures to ETS than others. The exposure in restaurants was 1.6–2.0 times as high as in the workplace and 1.5 times as high as in the average home. The exposure in bars was 3.9–6.1 times as high as in the workplace and 4.4–4.5 times the average levels in residential settings. These exposures are especially worrisome for people who work in these businesses because their total exposure is much higher.

### REGULATIONS ON HUMAN EXPOSURE

The number of regulations has accelerated in recent years in some parts of the country but lags in others. On the federal level, all federal buildings must be completely smoke-free whether owned or leased, and outdoor smoking areas must be restricted to ensure that no smoke will enter air intake ducts as mandated by Executive Order 13058. Smoking is banned on all commercial airplanes that operate within the United States whether foreign owned or domestic. OSHA prohibits smoking around certain substances. Warnings for the adverse health effects of smoking must be clearly labeled on all products, and there are severe restrictions on advertisements for tobacco products. The most effective regulations, however, are the result of state and local legislation. All state offices are smoke-free, as are most businesses. Many sporting events and other entertainment venues are smoke-free. In many areas, restaurants are smoke-free and there is even legislation proposed to ban smoking in bars and casinos. The goal for the Centers for Disease Control and Prevention is to reduce cigarette smoking to 12 percent and ETS exposure to 45 percent for nonsmokers and 10 percent for children by 2010.

See also ARSENIC; BENZENE; CADMIUM; CARBON DIOXIDE; CARBON MONOXIDE; DIOXIN; ETHYLBENZENE; INDOOR AIR POLLUTION; LEAD; NICKEL; NO<sub>x</sub>; PAH; PESTICIDES; SULFUR DIOXIDE; VINYL CHLORIDE.

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**toluene** Toluene is one of the most common chemical compounds and widespread environmental pollutants, but paradoxically comparatively very little is produced relative to that which is used and enters the environment. The reason for this paradox is that it is a natural component of crude oil and gasoline and never recovered but simply burned in gasoline engines and other combustion devices. It is the *T* in the ubiquitous and necessary BTEX (benzene, toluene, ethylbenzene, xylene) component of fuel. This "contained" toluene amounts to well more than 1 billion pounds (454 million kg) used per year. It also occurs naturally in the tolu tree, for which it is named. Toluene is a volatile organic compound (VOC) that also has anthropogenic sources and numerous applications in everyday life as well as industry. It was identified as a pollutant, however, in 851 of the first 1,350 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List) where it was tested, making it one of the most common and widespread pollutants in the world. Its adverse health effects and widespread distribution make it a concern. As a result, it was ranked as the 71st most hazardous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

### PRODUCTION AND USE

Pure toluene is a clear, colorless liquid with a strong smell that evaporates quickly. It is primarily produced to make benzene, accounting for 50 percent of all use in 1992. Other uses include gasoline blending to increase octane (30 percent), to produce toluene diisocyanate (7 percent), as miscellaneous chemicals (7 percent), and as solvents and in solvent extraction (6 percent). As a solvent, it is used in both industrial and consumer applications in aerosol spray paints,

wall paints, lacquers, inks, adhesives, natural gums, resins, spot removers, paint strippers, cosmetics, perfumes, and antifreeze. Of that which is turned into toluene diisocyanate, 90 percent is used to produce polyurethane foam. Flexible foam is used primarily in furniture (43 percent) and bedding (12 percent). Rigid foam (35 percent) is used primarily in insulation in housing and in appliances. The remaining 10 percent of toluene diisocyanate is used in floor finishes, wood finishes, paints, sealants, coatings, adhesives, and some plastic parts. The production capacity of the United States for toluene is nearly 2 billion gallons (7.56 billion L) per year, and yet only 800 million gallons (3.02 billion L) was produced in 1991. That year, some 62 million gallons (234.4 million L) was imported and 52 million gallons (197 million L) exported. Expected growth in production is estimated at 3 percent per year. Toluene diisocyanates are available in two isomers (2–4, 85 percent, and 2–6, 15 percent) and have been commercially available since the 1930s. Production in the United States increased from 616 million pounds (280 million kg) in 1985 to 869 million pounds (395 million kg) by 1995. At the same time, imports declined from 29 million pounds (13.2 million kg) in 1985 to 155,000 pounds (70,455 kg) in 2000 while exports increased from 9 million pounds (4.09 million kg) to more than 503 million pounds (228.6 million kg) during the same period. Toluene diisocyanates have similar properties to toluene's, but they can be crystalline solids, and they can be explosive when mixed with certain chemicals.

### ENVIRONMENTAL RELEASE AND FATE

Toluene is released into the environment through several pathways. Leaking storage tanks, illegal handling and dumping, and spills during transfer and transport are common ways it may be released to soil and surface water as a point source pollutant. It is a significant component of gasoline and is released during gasoline and other fuel releases, as well as refining operations. In this way, it can also be a nonpoint source pollutant. If soil is contaminated, toluene primarily evaporates or leaches into groundwater. If the soil is rich in organics, however, up to 97 percent of the infiltration toluene is adsorbed and becomes immobile. Within the soil, it is degraded by microorganisms, but it is slow to degrade at high concentrations because of its toxicity. It typically takes the microorganisms three to four days to become acclimated to the toluene in groundwater, and then it has been found to take as little as eight days to degrade it completely in some cases, but up to four weeks to degrade 2 percent of it in others. In shal-

low flowing surface water, toluene evaporates very quickly with an experimentally determined half-life of 2.9–5.7 hours. In another experiment with deep, still water and cold temperatures, the half-life was 13 days. Most toluene, however, is released into the atmosphere either directly or indirectly from soil and water. It is primarily released directly from evaporation of gasoline and other fuels, toluene-based solvents, motor vehicle exhausts, and emissions from fossil fuel-burning power plants and incinerators. In the atmosphere, it degrades rapidly through chemical reactions with photochemically produced pollutants or is washed out during precipitation. The half-life of this degradation under normal conditions is three hours to a little more than one day. In 1992, it is estimated that 193 million pounds (87.7 million kg) was released into the environment, 191 million pounds (86.8 million kg) of which (99 percent) was into the atmosphere, 84,000 pounds (38,180 kg) into surface water, 708,000 pounds (321,818 kg) into the land, and 1.6 million pounds (727,272 kg) into injection wells. Between 1987 and 1993, the top 10 states for environmental release of toluene in order were Texas and California by far, followed by Connecticut, Oklahoma, Virginia, Wisconsin, Illinois, Michigan, West Virginia, and South Carolina, primarily by petroleum refining and petroleum/coal products. Another major source of toluene exposure is cigarette smoke at about 80 micrograms per cigarette. Toluene diisocyanate is also primarily released to the air. Release is primarily through commercial handling, processing and production, emissions from industrial plants, and release from sprays, insulation, polyurethane foam, and coated fabric. The 1999 release of the two toluene diisocyanate isomers to the environment totaled nearly 112,000 pounds (50,900 kg).

### HEALTH EFFECTS FROM EXPOSURE

Exposure to toluene has been shown to produce several negative health effects. Acute inhalation exposure primarily affects the central nervous system. Low-dose exposure typically produces fatigue, confusion, loss of coordination, nausea, eye irritation, and impaired reaction time, as well as perception and motor control. High doses may result in narcosis and even death through respiratory failure. Long-term chronic exposure to toluene typically produces headaches, confusion and memory loss, tiredness, weakness, nausea, loss of appetite, loss of muscle control; problems with speech, vision, and/or hearing; decreased mental ability; and possible damage to kidneys. Toluene works synergistically with alcohol to damage the liver and with aspirin



and acetaminophen to damage the hearing. Most negative health effects on laboratory animals also involved the central nervous system. Long-term exposure to toluene also produced increased kidney, liver, lung, and heart weight in rats and mice, as well as necrosis of the brain and urinary bladder hemorrhage in rats. They also developed respiratory, hearing, and olfactory problems. Exposure of pregnant rats and mice to toluene resulted in damage to offspring, primarily in delayed skeletal development in rats and birth defects in mice. There are studies that suggest central nervous system abnormalities and developmental delays in humans. Toluene is classified by the EPA as group D: no clear indication that it is a human carcinogen. Toluene diisocyanate, however, is reasonably anticipated to be a human carcinogen. Experimental results of exposure in mice indicate cancerous conditions in the spleen, liver, ovaries, and other areas, whereas rats showed increased cancer development in the liver, pancreas, mammary glands, and related areas.

### REGULATIONS ON HUMAN EXPOSURE

There are several federal regulations regarding human exposure to toluene and toluene diisocyanate. The EPA has set a drinking water limit of one part per million (ppm) for toluene. They further recommend that a person not be exposed to more than 20 ppm for one day or 3 ppm for more than 10 days. Any release of more than 1,000 pounds (454 kg) of toluene to the environment must be reported to the National Response Center. Both the Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) limit workplace air to less than 100 ppm over an eight-hour-day, 40-hour workweek. In contrast, spills of 100 pounds (45.5 kg) of toluene diisocyanate must be reported to the National Response Center. OSHA recommends a ceiling concentration of 0.02 ppm of the toluene 2,4-diisocyanate isomer, and NIOSH set a designation of immediately dangerous to life and health (IDLH) for a 2.5-ppm exposure to the toluene 2,4-diisocyanate isomer.

See also AIR POLLUTION; BENZENE; ETHYLBENZENE; SUPERFUND SITES; TOBACCO SMOKE; XYLENE.

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**tornado** A tornado is the most destructive type of storm on Earth by virtue of its ferocious winds. A tornado can appear suddenly and demolish whole towns within minutes. Fortunately, it is small in size (typically hundreds of feet across) and short-lived, and the more destructive varieties are regionally restricted. For these reasons, a hurricane, which is much larger and longer-lasting, is capable of much more extensive amounts of total damage. The threat to the environment from a tornado results completely from the structures and objects that it can destroy at the surface. Not only can it wreck habitats and kill animals and vegetation, but also it can rupture and destroy virtually any manufacturing, transportation, and storage structure for dangerous chemicals on the surface. It is in this way that a tornado is the greatest threat to people and the environment.

### FORMATION OF A TORNADO

A tornado forms from a thunderstorm under very specific conditions. A thunderstorm forms in hot, moist, and low-density air (rising) at the ground surface that is affected by cooler, denser air (sinking) aloft, thus producing unstable conditions because of the inverted density structure. These conditions involve vigorous vertical circulation of air to high levels in the troposphere as the air density attempts to equilibrate. The circulation of air occurs in convection cells that may be individual, or single-cell storms; multicellular storms; with many convection

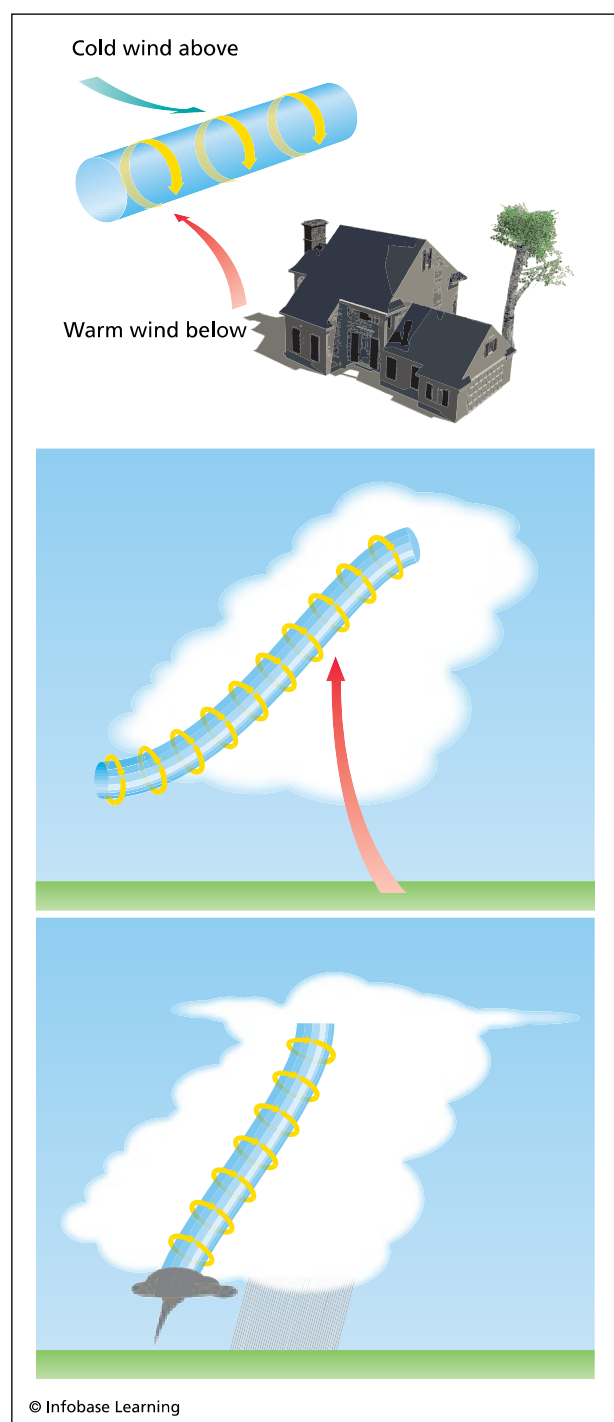
cells; or supercell storms, if the circulation is large and intense. A tornado may form in multicell storms, but the supercell storm is by far the primary tornado producer.

The dominant direction of circulation in the storm determines its nature. A storm in which upward movement dominates draws warm moist air to higher, cooler levels and causes high amounts of condensation. This kind of storm is characterized

by heavy rain but not much wind. Other kinds of storms may be dominated by downward movement of air, which causes substantial straight-line winds and microbursts but little rain. The most intense storms are characterized by intense upward and downward movement of air. The upward movement causes the storms to grow to great height. They take on a characteristic anvil shape with very thick, dark cumulus clouds in the body and an abruptly flat top that drags behind the storm. The intense circulation in both directions can draw the freshly condensed rain to high levels, where it can freeze, fall, condense more moisture, and be swept back upward to have a new coat of ice added to it. A number of such cycles, as is common in a supercell, produce hail, the size of which depends upon the number and intensity of the cycles it travels through. A strong upward and downward motion is also necessary to produce a tornado. That is why hail is commonly associated with tornadoes.

Surprisingly, many of the storms that bear tornadoes begin with horizontal rather than vertical motion. A burst of cool, dry air at height rides over warm, moist air at ground level. The cool air is denser and sinks, while the less dense warm air rises. This creates a rolling effect, or horizontal rotation, in the now-unstable atmosphere. As the result of instability of the cold airflow, variations along the length of the horizontal rotation, and drag on the surface, the developing storm flips up on end to produce a vertically rotating, or spinning, cell. The cell may spin either counterclockwise, as is common for all low-pressure disturbances in the Northern Hemisphere, or clockwise. The now-vigorously-spinning mesocyclone develops into a supercell. Although the upward motion makes the storm grow strong, it is the downward motion that forms the tornado. The first sign of the downward motion is the development of mammatus clouds. Next, a wall cloud extends below the storm. The wall cloud is a circular band of clouds that hang below the main cloud deck. It is from the center of the wall cloud that the tornado drops.

Supercells with tornadoes are not symmetric. Part of the storm is dominated by updraft and part by downdraft. The updraft area is characterized by



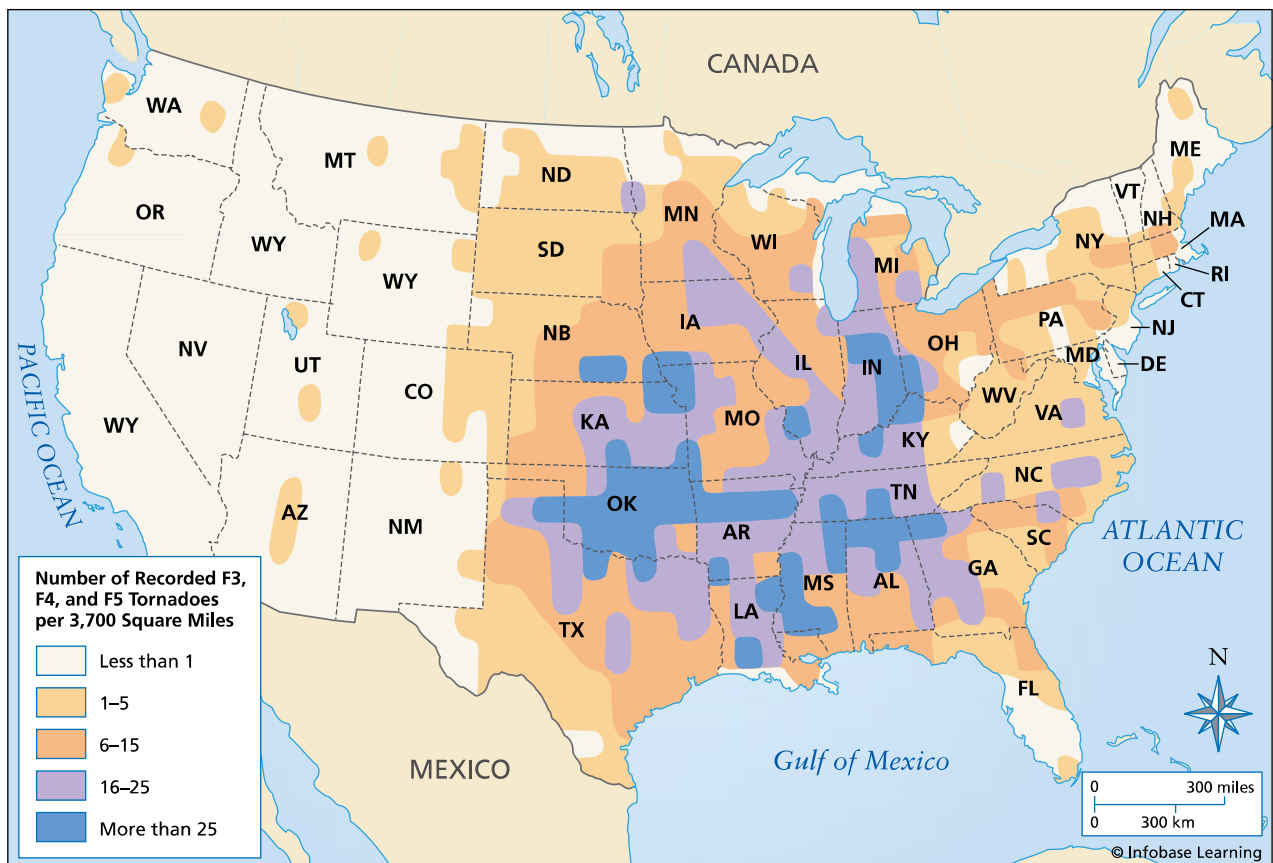
**Three-step model for the development of a tornado. The first step (top) is the convergence of oppositely directed cold air aloft and warm air below, causing horizontal rotation. In step two (middle), the horizontally rotating cell is swept upward by rising air to produce a large rotating cloud mass called a supercell storm or mesocyclone. In step three (bottom), if conditions are right, a tornado is spawned beneath the mesocyclone accompanied by thunderstorms.**

heavy rain, whereas the downdraft area is relatively dry. This means that the tornado is on the dry side of the storm. In many storms, the tornado occurs on the southwest side of the storm. It can be seen on the Doppler radar used by meteorologists as a distinct hook in the intense, or “red,” part of the storm.

### CLASSIFICATION OF A TORNADO

The classification of the strength of a tornado is based purely upon wind speed. The standard classification scheme up until 2007 is known as the Fujita scale: It typically ranges from F0 to F5, though F6 (*F* for *Fujita*) tornadoes are possible in extremely rare cases. These F classifications are designated according to the following criteria:

- **F0 tornadoes.** Also known as gale tornadoes, F0 storms have wind speeds of 40–72 miles (64–116 km) per hour. They produce some damage to chimneys, break branches off trees, push over shallow-rooted trees,
- and damage sign boards. The frequency of this level of storm is 29 percent of total, though other data suggest that with F1 they constitute about 74 percent.
- **F1 tornadoes.** These are classified as moderate tornadoes with wind speeds of 73–112 miles (117–180 km) per hour. The damage from these storms includes peeling the surface off roofs, pushing mobile homes off their foundations or overturning them, pushing moving autos off roads, and possibly destroying attached garages. The frequency of this level of tornado is about 40 percent.
- **F2 tornadoes.** These storms are classified as significant tornadoes with wind speeds of 113–157 miles (181–252 km) per hour. They inflict considerable damage including tearing roofs off frame houses, demolishing mobile homes, pushing over train boxcars, uprooting or breaking large trees, and turning light objects into missiles. The frequency of this



**Map of the United States summarizing the annual distribution of F3, F4, and F5 tornadoes, which averaged more than 3,700 square-mile (9,583 km<sup>2</sup>) blocks between 1950 and 1998. (The greatest risk is in the central and southern Midwest.)**  
 (Source: NOAA, Storm Prediction Center Statistics)

level of tornado is about 24 percent, though other data suggest that with F3 storms they make up 25 percent of the total.

- *F3 tornadoes.* These severe tornadoes have wind speeds of 158–206 miles (253–330 km) per hour. Damage from them is intense, including tearing the roof and some walls off well-constructed houses, overturning trains including the engine, and uprooting most trees in the forest. The frequency of this level of tornado is about 6 percent.
- *F4 tornadoes.* These devastating tornadoes have wind speeds of 207–260 miles (331–417 km) per hour. They can level well-constructed houses and hurl structures with weak foundations for some distance. Cars are thrown and large objects can become missiles. Only about 2 percent of storms reach this strength, though some studies suggest that with F5 tornadoes they constitute only about 1 percent of the total.
- *F5 tornadoes.* These incredible tornadoes have wind speeds of 261–318 miles (418–509 km) per hour. If these storms strike, strong frame houses are lifted off foundations and carried considerable distances before disintegrating. Massive missiles are sent flying for distances in excess of 325 feet (100 m). They can remove the bark from trees and badly damage steel-reinforced concrete structures. Far less than 1 percent of tornadoes reach this intensity.
- *F6 tornadoes.* Only one or two of these inconceivable tornadoes with wind speeds of 319–379 miles (510–606 km) per hour have ever been proposed, much less documented. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl patterns. The damage is so intense that it may never be identifiable through engineering studies.

Over the years, the Fujita scale has revealed several weaknesses. It is a very subjective scale in that it is based solely on the damage caused by the tornado. It does not distinguish the damage among different types of construction. It is difficult to apply in the absence of damage indicators. For example, if the  $\frac{3}{4}$ -mile- (1.2-km-) wide tornado does not hit any structures, a Fujita scale designation cannot be assigned. It is subject to bias of observers and is based on the worst damage observed even if it is one build-

ing or house that shows such damage. It also overestimates wind speeds in tornadoes greater than F3. For these and other reasons, the meteorological profession abandoned the Fujita scale for the Enhanced Fujita scale.

The Enhanced Fujita (EF) scale was implemented in the United States on February 1, 2007. The EF scale relies on 28 designated damage indicators to determine the tornado's rating. Each one of these indicators has a description of the typical construction for that category of indicator. The degree of damage (DOD) can then be determined by observation for each indicator present. By comparing the DOD with a calibrated guide, an expected estimate of wind speed can be determined. The damage observed is assigned a lower and an upper bound of wind speed. The following table is a list of the 28 features from which wind speed may be estimated.

By using as many features as can be identified, the wind speed can be estimated. The advantage of this system is that there are multiple sources of estimation including vegetation. This is much more inclusive and ostensibly more accurate than the old Fujita scale. The wind speed is interpreted for a three-second gust and the EF scale is assigned. The scale is as follows:

EF-0	65–85 miles (104–137 km) per hour
EF-1	86–110 miles (138–177 km) per hour
EF-2	111–135 miles (178–217 km) per hour
EF-3	136–165 miles (218–264 km) per hour
EF-4	166–200 miles (265–320 km) per hour
EF-5	>200 miles (320 km) per hour

Although they are supposed to be converting to the EF scale, most weather reports in the media still rely on the older Fujita scale. For most purposes, the older scale is still descriptive enough to rate tornadoes in terms of power, and it is easier to understand for most people. For technical purposes, the EF scale is superior. Environmental effects of tornadoes are better classified by the EF scale because small variations in damage can greatly affect the amount of pollutant released as the result of a tornado. The EF scale is also superior for planning purposes such as building codes for facilities that could release toxicants during a tornado. In this case, the small differences could be the difference between repairable damage and an environmental disaster.

## PATH OF A TORNADO

By far, most funnel clouds that descend from the base of a storm do not reach the ground. Many funnel clouds are generated, but few become tornadoes.



### STRUCTURES WHOSE DAMAGE IS USED TO DETERMINE RANK ON ENHANCED FUJITA (EF) SCALE

1)	Small barns, farm outbuildings (SBO)
2)	One- or two-family residences (FR12)
3)	Single-wide mobile home (MHSW)
4)	Double-wide mobile home (MHDW)
5)	Apartment, condominium, townhouse (three stories or less) (ACT)
6)	Motel (M)
7)	Masonry apartments or motel (MAM)
8)	Small retail building (fast food, etc.) (SRB)
9)	Small professional building (doctor's office, branch bank) (SPB)
10)	Strip mall (SM)
11)	Large shopping mall (LSM)
12)	Large, isolated ("big box") retail building (LIRB)
13)	Automobile showroom (ASR)
14)	Automotive service building (ASB)
15)	School: one-story elementary (interior or exterior halls) (ES)
16)	School: junior or senior high school (JHSH)
17)	Low-rise (one- to four-story) building (LRB)
18)	Midrise (five- to 20-story) building (MRB)
19)	High-rise (more than 20 stories) (HRB)
20)	Institutional building (hospital, government, or university) (IB)
21)	Metal building system (MBS)
22)	Service station canopy (SSC)
23)	Warehouse (tilt-up walls or heavy timber) (WHB)
24)	Transmission line tower (TLT)
25)	Free-standing tower (FST)
26)	Free-standing pole (light, flag, luminary) (FSP)
27)	Tree—hardwood (TH)
28)	Tree—softwood (TS)

Most tornadoes begin as low-rank storms (EF-0) and may ascend and descend several times before becoming established. Once they are descended, or "on the ground," they can intensify. They typically

begin as low, short, and thin funnels. As they intensify, the funnel grows wider and lengthens. The path of the tornado is variable. Some travel in straight paths, whereas others tend to sweep back and forth. The longer the funnel, the more they sweep. The forward speed of a tornado is also variable, ranging from 20 miles (32 km) per hour to upward of 60 miles (96 km) per hour. The forward speed impacts the total wind speed just as it does with hurricanes. Where the wind direction is parallel to the movement direction, the wind speed and forward speed are added to produce a high-velocity side. In most tornadoes, this is the right side of the tornado in the United States. On the left side, the forward motion is subtracted from the wind speed, producing lower wind speeds, in most cases.

Toward the end of the life of the tornado, it may become ropey and make strange patterns. Tornadoes primarily stay on the ground for a few seconds to a few minutes, especially for low-rank storms. Larger storms remain on the ground for longer periods. They can be as short as 30 minutes or less and as long as three hours in the most severe cases.

### POLLUTION FROM A TORNADO

Pollution from a tornado can have a number of sources. The first sighting of a tornado on the ground is typically the debris that continuously emanates from the storm in all directions. A tornado may generate several tons of debris that can spread all over the countryside. The debris can include fragments of all kinds of construction materials, many of which can be hazardous. The strong winds pulverize much of the material and produce a huge amount of dust or particulate that may circulate around the area for days, depending upon the amount of ensuing rain. The particulate may include leaded paint, asbestos, glass fibers from insulation, and a number of other pollutants.

The other main source of pollution is generated by the structures that are destroyed by the intense wind. Facilities, including manufacturing plants and storage tanks, can be ruptured or destroyed in a tornado. This would create a spill that would enter the surface runoff, eventually entering surface waters. Most spills would be fuel of some sort, but in areas of chemical manufacturing, they could be a number of possible chemicals. Other commercial enterprises could also store dangerous chemicals such as trichloroethylene (TCE) in dry cleaners that would also enter the soil or water. Tanker train cars can also be carrying dangerous chemicals that can be released if they are ruptured. These spills have serious environmental consequences. There was even a possible

doomsday scenario in a movie of a tornado destroying a nuclear power plant and causing a meltdown. Although this has never happened, it is not out of the question.

See also HURRICANES AND POLLUTION; PARTICULATE; TCE.

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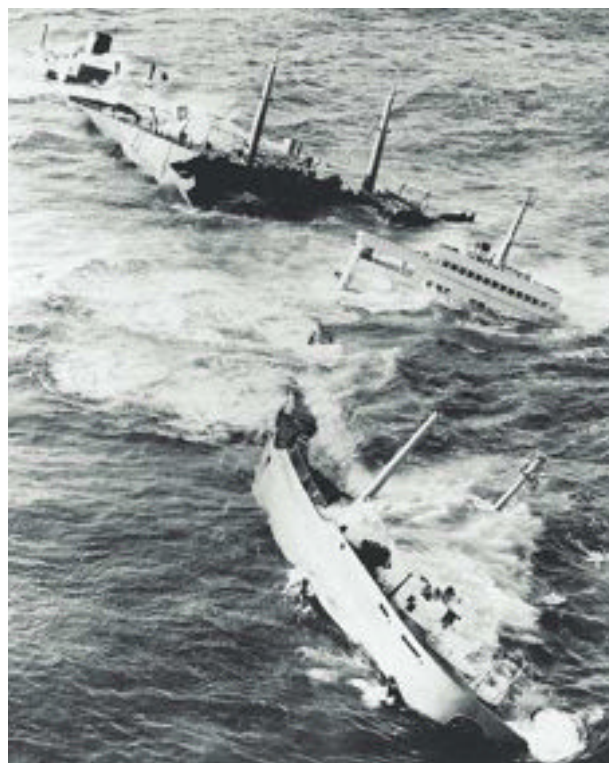
**Torrey Canyon oil spill Scilly Islands, United Kingdom (March 18–30, 1967) Water Pollution** As one of the world's first supertankers, the *Torrey Canyon* was the 13th largest ship ever in commercial service (120,000 tons [108,862 metric tons]). Originally built in the United States in 1959 as a standard-sized (60,000 tons [54,431 metric tons]) tanker, it was cut in half and enlarged in Japan. With the addition of several new cargo bays, at almost 1,000 feet (305 m) long and more than 125 feet (38 m) wide, it thus became a supertanker, an oceangoing vessel with a capacity of more than 75,000 tons (66,964 metric tons). Supertankers were being developed to meet the demands of the United States and Europe for inexpensive Middle Eastern oil. Proven petroleum reserves in the known developed oil fields began to decline after World War II, and the price of oil started to rise. This made Middle Eastern supplies more economically attractive. The problem was getting the oil to market. There were few overland pipelines and none that could effectively connect wellheads in Kuwait or Iraq to refining and distribution centers in New Jersey, Louisiana, or Milford Haven, United Kingdom, and supertankers were the solution. Crude oil could be extracted and stored in the Middle East and loaded in enormous quantities

onto large vessels that can carry it directly to market for final processing and sale. However, risks were associated with moving such large quantities of toxic substances through and near ecologically sensitive and fragile ocean and estuarine settings.

### BACKGROUND

The supertanker *Torrey Canyon* was owned by Union Oil of California but had been chartered to British Petroleum (BP). It was registered in Liberia and was operated by a mostly Italian crew. It picked up a cargo of about 30,000,000 gallons (114 million L) of crude oil at Mena al-Ahmadi, Kuwait, on February 17, 1967. After about a month of uneventful sailing, the ship had rounded the Cape of Good Hope (too big to fit through the Suez Canal), passed the Canary Islands, and, by the evening of March 17, had reached the Isles of Scilly off the coast of England. The ship's destination was Milford Haven, a major industrial port in southeastern England. The *Torrey Canyon* was to unload its cargo at a BP refinery and begin preparations for the return voyage to the Middle East.

The standard approach to Milford Haven for a ship the size of *Torrey Canyon* was to sail seaward (east) of the Scilly Isles. Otherwise, it would have to



The grounded U.S. tanker *Torrey Canyon* on a reef off the Scilly Islands, England, March 1967 (AP Images)

thread its way through a narrow (20-mile- [32-km-] wide) gap between Lands End, a spit of land jutting from the east coast of Cornwall, and the rock-strewn coast of the Scillys. The Scilly Islands enjoy almost year-round sunshine, because of the moderating ocean climate. They are a popular vacation spot and tourist attraction. Among the islands' main exports are flowers, which, because of the almost year-round sunshine and relatively mild climate, begin to bloom much earlier there than in other parts of the United Kingdom. Bird-watchers are also attracted to the Scillys, because rare species from all parts of Europe commonly use the islands to rest and eat before continuing seasonal migrations.

There are 55 islands in the archipelago, five inhabited and 50 without permanent residents, as well as some 90 large half-submerged rocks. The islands are small, with Saint Mary's, the largest, only three miles (4.8 km) across. They are composed of granite, which weathers into a gritty soil and produces light-colored, sandy beaches. The blocky cliffs and the submerged rocks circling many of the islands have long been known to pose a serious threat to shipping.

### THE ACCIDENT AND OIL SPILL

Most environmental disasters are not caused by a single event, but rather a series of small actions, which combine into a catastrophe. The *Torrey Canyon* oil spill is a good example. As the ship neared the end of its 6,000-mile (9,656-km) trip, a navigational error caused it to enter the relatively narrow waterway between Lands End and the Scilly Isles. These are very dangerous waters for a ship as big and as difficult to maneuver as the *Torrey Canyon*. The captain was made aware of the error and yet issued a "hold course" order. It was later found that if the *Torrey Canyon* did not make Milford Haven by the next day, it would have had to wait six days for a tide high enough to allow it to enter the shipping channel and dock. The *Torrey Canyon* continued under way at almost full speed, 17 knots or about 20 miles per hour (32 km/h).

The captain and crew were not particularly concerned because the seas were calm, the weather clear, the charts accurate and up-to-date, and the ship one of the most modern and reliable vessels ever built. As long as they stayed well clear of the Scillys, particularly the notorious Seven Stones Reef, an area of submerged granitic boulders, the *Torrey Canyon* was not in any real danger. An inexperienced junior officer on his first trip, however, made a second navigational error, plotting the location of the ship well clear of Seven Stones when actually it was within three miles (4.8 km) of these hazards. The

captain discovered the error just in time and quickly ordered a series of emergency course changes. The ship failed to respond, however, because the helmsman neglected to disengage the autosteering mechanism, which had been preset to maintain the most direct course to Milford Haven. On March 18, 1967, the *Torrey Canyon* struck Pollard's Rock in Seven Stones Reef and a 17-foot- (5.2-m-) long gash was ripped through six of the oil storage compartments. Over the next 12 days, the ship's entire cargo of 36 million gallons (136 million L) of crude oil was released into one of the most ecologically sensitive and pristine areas of the British Isles.

This was the first major spill from a supertanker, and no one was sure how to respond. The crew was evacuated with one lost at sea during the rescue effort, and a Dutch salvage company attempted to refloat the vessel by removing it from the reef. A second crewman was killed in an explosion as salvage crews attempted to transfer the oil remaining onboard to another tanker. As a result, other recovery efforts were quickly abandoned. As oil continued to leak from the gashes, the Royal Navy decided to bomb the *Torrey Canyon* and set the rapidly spreading oil slick on fire using napalm. Fighter jets dropped almost 100 incendiary bombs on the stationary ship, many of which missed their target. They were eventually successful in blasting the stricken vessel off the reef and sending it to the ocean bottom. Some of the floating oil was also ignited in the attack. All of this was done under the watchful eye of the British prime minister Harold Wilson, who was vacationing on the Scilly Islands when the *Torrey Canyon* went aground. Unexploded ordnance warnings are still in effect for divers who wish to explore the sunken wreck of the *Torrey Canyon*.

### THE CLEANUP

The oil slick released by *Torrey Canyon* spread out to cover an area of 270 square miles (700 km<sup>2</sup>). Approximately 120 miles (192 km) of English coastline and 50 miles (81 km) of beach in France was contaminated. A variety of cleanup efforts were used on the oil that was fouling these shorelines. Some 1,400 British soldiers were mobilized and, using a quickly formulated mix of naturally absorbent straw and grose (a haylike weed), recovered about 1 million gallons (3.8 million L) of oil. The French also used chalk mixed with stearic acid, a waxlike solid used in soaps, to absorb and break down the oil washing up on their beaches. Five million gallons (18.9 million L) of oil treated in this manner was recovered by more than 3,000 French troops working for weeks after the spill.



At sea, skimmer pumps recovered oil floating on the water, and more than 40 ships began to release more than 10,000 tons (9,072 metric tons) of detergents to emulsify and disperse the oil. Unfortunately, although the dispersant was reasonably effective at breaking up the floating petroleum, these previously untested chemicals proved to be extremely toxic to marine life. Later studies showed that the dispersants did more ecological damage than the oil. Wave-beaten rock and beaches that received only a light oiling recovered in about five to eight years. Similar areas that received a coating of dispersant took nine to 10 years to return to their ecological prerelease state. Along those stretches of beach where dispersants were extensively and repeatedly used, many types of marine flora and fauna have still not reappeared.

The spill occurred during the peak of the northern migration for many varieties of birds. Several studies estimated the number of birds killed at about 200,000. There was a 1 percent survival rate for the thousands of oil-covered birds picked up from beaches by volunteers. With the best of intentions, volunteers washed the birds with detergents to remove the crude oil. This washing also removed the natural coating of oil seabirds need to repel water and retain body heat. Also, as the birds preened, they ingested residual amounts of detergent, which either fatally poisoned them or made them extremely ill.

### THE AFTERMATH

The long-term environmental and economic effects of the spill were devastating. More than 40 percent of the 1967 oyster harvest was destroyed. Oysters are an important dietary as well as financial supplement for island residents. There was a literal explosion of seaweed and algal growth levels as a result of the nitrogen and other nutrients present in the dispersants that dissolved into the seawater. This overwhelmed native marine plants and disrupted the local food web for many years. There was an 80 percent drop in tourism. It would take another five years to recover to prespill levels. The human costs included the two fatalities that occurred during the evacuation and attempted salvaging of the *Torrey Canyon*. The ship's captain, after having his license revoked for incompetence, died several years later. The largest insurance claim in maritime history to that date was filed for the incident at \$16 million for the ship and \$23.2 million for the cleanup, including the RAF bombardment.

The incident, however, drew attention to the potential for such disasters. In 1969, the international Civil Liability Convention (CLC) was estab-

lished. The CLC held shipowners strictly liable for environmental and ecological damage caused by the release of oil, whether or not that release occurred because of accident, mechanical failure, or negligence. A few years later in 1973, the International Convention for the Prevention of Pollution from Ships was adopted. This treaty set operational and performance standards for oil tankers and other commercial vessels involved in the transport of hazardous or potentially hazardous cargo.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS; WATER POLLUTION; WAVES.

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**toxaphene** When dichlorodiphenyltrichloroethane (DDT), the most widely used pesticide, was banned in 1972, there was an urgent need for a replacement. Toxaphene replaced DDT as the pesticide of choice for the mid- and late 1970s. The problem was that toxaphene is probably more toxic than DDT and nearly as persistent in the environment. For that reason, it, too, was banned in the United States in 1982, and another pesticide had to be found. Toxaphene is a chlorinated organic pesticide that is a mixture of at least 175 and as many as 670 separate compounds. It is also known by trade and chemical names such as Chlorinated camphene, Octachlorocamphene, Camphochlor, Agriocide Maggot Killer, Alltex, Crestoxo, Compound 3956, Estonox, Fasco-Terpene, Geniphene, Hercules 3956, M5055, Melipax, Motox, Penphene, Phenacide, Phenatox, Strobane-T, Toxadust, Toxakil, Vertac 90 percent, Toxon 63, Attac, Anatox, Royal



Brand Bean Tox 82, Cotton Tox MP82, Security Tox-Sol-6, Security Tox-MP cotton spray, Security Motox 63 cotton spray, Agro-Chem Brand Torbidan 28, and Dr Roger's Toxene. It has been found in 58 of the first 1,430 U.S. Environmental Protection Agency (EPA)-designated Superfund sites (National Priority List) in which it has been tested. As a result of the widespread distribution and adverse health effects from exposure, it was ranked number 31 on the 2007 CERCLA Priority List of Hazardous Substances, which includes 275 pollutants.

### PROPERTIES, USES, AND PRODUCTION

Toxaphene is an organochlorine insecticide that is one of the polychlorinated bicyclic terpenes with chlorinated camphers. In its base form, it is a yellow or amber waxy solid with a turpentine odor; it was marketed as wettable powders, emulsifiable concentrates, granules, dusts, oils, and emulsions. Toxaphene was first commercially produced in 1947 and more than 900,000 tons (409,000 metric tons) was reportedly produced between then and 1974. Peak production in the United States was in 1975 at 59.4 million pounds (27 million kg) but declined 90 percent by 1982 because of the bans and restrictions. The average consumption in the United States between 1966 to 1979 was 34 million pounds (15.5 million kg) per year. By 1977, the annual consumption was up to 40 million pounds (18.2 million kg) per year but dropped to 6.6 million pounds (3 million kg) by 1982, when its use in the United States was banned. During peak consumption, 85 percent was used for cotton, 7 percent for insects on livestock and poultry, 5 percent for other field crops, 3 percent for soybeans, and 1 percent for sorghum. Over its entire history, 50 percent was used for cotton, 17 percent for vegetables, 17 percent for livestock, and 12 percent for soybeans. It was effective against all major cotton insects, mealybugs, worms, scab mites, hornflies, lice, armyworms, cutworms, and grasshoppers, as well as control of certain species of fish in lakes. It is still used for mealybug and moth control on pineapples, and weevil control on bananas in the Virgin Islands and Puerto Rico, among others.

### ENVIRONMENTAL RELEASE AND FATE

As with other pesticides, virtually all toxaphene that was produced was released as nonpoint source pollution in widespread dispersion. Since the ban, it has only been released as point source pollutant from leaks and spills at production, transportation, storage, and waste facilities in the United States. Toxaphene was primarily released into the soil, where

evaporation from the surface was a significant form of removal (15.4–30.8 pounds [7–14 kg] per hectare per year). That which did not evaporate adhered strongly to soil, where it does not hydrolyze, photolyze, or biodegrade to any extent under aerobic conditions. The half-life of toxaphene in soil has been calculated at one to 14 years, but one study found 45 percent of that which had been applied in 1951 was still present 20 years later. The biodegradation under anaerobic conditions is much faster, with a half-life as quick as six weeks. Very little toxaphene leaches into the groundwater system, but erosion of toxaphene-bearing soil can result in surface water contamination. In surface water, that which does not evaporate from the surface adheres to particles in the water and settles into the sediment, where it is also impressively persistent. In one study of Canadian lakes that had been treated for unwanted fish species, toxaphene was still found to be at toxic levels five years after the application. In the atmosphere, toxaphene is also very persistent though not as persistent as in soil. It typically attaches to particulate and slowly breaks down by photolysis and photochemical reactions with hydroxyl radicals. Transport in the atmosphere has been found to be up to 750 miles (1,200 km).

Perhaps even more impressive than its persistence is toxaphene's ability to bioaccumulate. Bioconcentration factors for fish have been found to range from 3,100 to 69,000 times ambient levels. Other aquatic and terrestrial organisms also show bioaccumulation but not to this degree. It is primarily through consumption of animals with bioaccumulated toxaphene that humans are exposed to it.

### TOXICOLOGY AND HEALTH EFFECTS FROM EXPOSURE

Exposure to toxaphene results in numerous adverse health effects. Acute exposure first causes nausea and vomiting but primarily causes effects on the central nervous system including hyperexcitability, restlessness, muscle tremors and spasms, and periodic to continuous convulsions, possibly leading to brain damage and even death by respiratory failure at high doses. It can also cause hyperthermia; paresthesia of the tongue, lips, and face; skin irritation; and damage to the liver. Long-term chronic exposure results in headaches, nausea, fatigue, muscle twitching, vision problems, and damage to the liver, kidneys, adrenal glands, blood system, and immune system, depending upon dosage. It has also been shown to cause minor changes in fetal development and decreased fertility in laboratory animals. Toxaphene is regarded as reasonably anticipated to be

a human carcinogen by the Department of Health and Human Services. It has been shown to cause increased incidence of cancer of the liver and thyroid in laboratory animals, but there is no indication of cancer in humans at this point.

### REGULATIONS ON HUMAN EXPOSURE

The EPA banned the use of toxaphene in the United States and its territories in 1990 and the import of any food with toxaphene residues in 1993. They limit the amount of toxaphene in drinking water to three parts per billion (ppb) under the Safe Drinking Water Act. They further require that the release of one pound (0.45 kg) or more must be reported to the National Response Center. OSHA set their permissible exposure limit (PEL) to 0.5 milligram of toxaphene per cubic meter of workplace air during an eight-hour-workday, 40-hour workweek.

See also AGRICULTURE AND POLLUTION; BIOACCUMULATION AND BIOMAGNIFICATION; DDT; PESTICIDES; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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**toxicology** Under most legal definitions, poisons are chemicals that cause illness, injury, or death when taken in small quantities, usually about 50

mg per 1 kg of body weight or less. This is about  $\frac{3}{4}$  teaspoon (3.7 mL) for the average adult and about  $\frac{1}{8}$  teaspoon (0.6 mL) for a two-year-old child. The word *poison* is from the Latin *potio*, which means "drink." Their effect has to be immediate or very near term, and most toxicologists classify a poison as having an LD50 of 50 mg or less. LD50 means that a substance has a lethal effect at 50 mg per 1 kg of body weight (LD or lethal dose) on 50 percent of the test population within 14 days. Toxicologists have measured LD50s on many substances: aspirin, for example, has an LD50 of 1,000 mg per 1 kg of body weight; caffeine's LD50 is 192 mg; and sodium cyanide has an LD50 of 6 mg (see the following table).

People have been poisoning each other intentionally for thousands of years. The Romans became particularly adept at using poisons, even establishing special "poison schools" to teach and pass along the craft to promising students and future generations. Professional poisoners often tested the potency of their formulas on animals, slaves, or convicts. Poisons available during Roman times were developed from three sources: animals, minerals, and plants. Animal poisons were not well studied in ancient times, being difficult to extract and store. Cantharadine, a skin irritant formed from the husks of dried blister beetles (later called Spanish fly), was popular, as were such unlikely poisons as bull's blood, toads, and salamanders. Venom from poisonous insects, snakes, spiders, and scorpions was well known but rarely used in homicide. Mineral poisons, primarily lead, mercury, copper, arsenic, and antimony salts, also were known but seldom used. The fatal doses were high and difficult to introduce into food or water because of their distinctive taste.

Poisons made from plants were most frequently used. They included extracts from henbane, datura, deadly nightshade, mandrake, aconite from monkshood, hemlock, hellebore, colchicum from autumn crocus, yew, and opium. Cyanide (LD50 1.1 mg), distilled from peach, apple, and other fruit pits, was used in judicial executions by the ancient Egyptians ("penalty of the peach") and Romans ("the cherry death"). Cyanide also was used as arrow and dart poison by the Mayan, who extracted it from the yucca plant. Strychnine, one of the deadliest poisons ever developed (LD50 of 0.2 mg), was apparently not known to the Romans but was used in India, where it was extracted from the seeds of the *Strychnos nux-vomica* tree.

Poisons are different from toxins, although both scientists and nonscientists often use the two terms interchangeably. Strictly speaking, toxins are substances produced by biological activities that cause

## TOXICITY RATING AND DOSAGE FOR SEVERAL SUBSTANCES

Toxicity Rating <sup>1</sup>	Comparable Oral LD50 (single dose to rats) mg/kg	Probable Lethal Dose for Adults	Substance	Oral LD50 (mg/kg) <sup>2</sup>
Extremely toxic	1 or less	one drop (1 grain)	Aldicarb (insecticide)	1
Highly toxic	1–50	1 tsp (4 mL)	Parathion (insecticide) Kerosene	3 5–49
Moderately toxic	50–500	1 fl. oz. (30 mL)	Nicotine Caffeine	53 192
Slightly toxic	500–5,000	1 pint (600 mL)	Codeine Aspirin	600 1,240
Practically nontoxic	5,000–15,000	1 quart (1 L)	Sodium Chloride (table salt)	3,320
Relatively harmless	15,000 or more	1 quart (1 L)	Sucrose (table sugar)	29,700

Notes: (1) Toxicity rating based on the Hodge and Sterner Toxicity Class scale

(2) Oral LD50 taken from NIOSH Registry of Toxic Effects of Chemical Substances

injury, illness, or death at low concentrations. Examples include the bacterial proteins that cause tetanus and botulism. Modern usage, however, has broadened the definition of *toxic* to include harmful substances that are nonbiologic in origin (e.g., toxic waste).

Toxicologists evaluate the effects of poisons primarily through the use of animal studies (i.e., experiments on rats, monkeys, guinea pigs, etc.). These studies provide general information on how poison is metabolized or incorporated into the physiological systems of animals. They also provide clues as to how these substances may affect human health.

An important component in the understanding of poisons is that of dose. A dose is a quantity or amount of an active agent that is taken into the body at any one time. Most commonly associated with medicine, dose can also be applied to the accidental, unintentional, or unknowing intake or ingestion of a poisonous or toxic substance. There is a saying among toxicologists that the “dose makes the poison.” The inhalation of a 0.7-ounce (20-mg) mist of cromolyn sodium solution dissolved in 0.06 fluid ounce (2 mL) of water is a very effective treatment for asthma. At much higher concentrations, it may cause adverse reproductive effects in pregnant women. Almost every substance can be toxic. Water, which humans need to consume about one half-gallon (2 L) of every day, has a 28-hour LD50 of 180,000 mg per 1 kg of body weight. If a person weighs 150 pounds (68 kg) and drinks about five gallons (19 L) of water in less than a day, there is a good chance he or she will become very sick or even

die. That quantity of water consumed over so short a time quickly dilutes electrolytic balances, and the excess fluid interferes with respiration, cardiac activity, and brain function.

Generally, as dose increases, toxicity increases, but this varies with the substance. The toxic effects of many substances do not become apparent until a minimal amount is ingested. This is called the threshold dose, and it is the lowest dose or concentration that causes a detectable response in a population. Above the threshold dose, a response is induced—people become sick or die. Below the threshold, there is no observable effect or response. This relationship is illustrated in a dose-response curve, which tracks the adverse response that will occur with any given dose. For example, in a dose-response curve for smokers, mortality rates are plotted against the quantity (or dose) of cigarettes smoked. As the number of cigarettes smoked per day (dose) increases, so does the mortality rate (response).

## TOXIC EFFECTS ON ORGANISMS

When a toxic or poisonous compound enters an organism, it has an acute, chronic, or subchronic effect. Acute toxic effects occur when a single dose or amount of a substance causes severe biological harm (sickness or injury) or death shortly after exposure (usually within 24 hours). For example, when a prison inmate is injected with a high concentration of potassium chloride, acute toxicity results. This method of execution (lethal injection) quickly

results in death because it disrupts the neurological mechanisms that signal the heart to contract.

In chronic toxicity, illness or death is caused by repeated or long-term exposure, usually over more than 50 percent of an organism's life span, to low doses. For humans, chronic exposure typically occurs over several decades. For experimental animals (laboratory rats or mice), chronic exposure is typically considered to be more than three months. For example, in 1997, 25,000 people died in the United States of cirrhosis, a chronic liver disease caused by repeated, long-term exposure to alcohol. From an environmental perspective, chronic toxicity is more commonly associated with chemicals that bioaccumulate. In the late 1950s, in Minimata, Japan, hundreds of people became chronically ill (most had central nervous system damage) through the daily, long-term ingestion of fish from waters that were severely polluted with mercury.

Subchronic toxic effects are observed after repeated daily exposure over a significant part of an organism's life span, usually not exceeding 10 percent. For people, this may mean exposures of less than 10 years. For experimental animals, the period of exposure may range from a few days to six months. In practice, subchronic exposures are longer than acute exposures, but shorter than chronic exposures.

Beryllium is an alloying material used in the manufacture of high-performance aircraft parts and missile components. As a result of its widespread industrial applications, toxicologists have been able to determine that an acute health effect (berylliosis) occurs when people inhale beryllium dusts at concentrations ranging between 2 and 1,000 mcg/m<sup>3</sup>. Berylliosis develops shortly after exposure to these types of high concentrations and is characterized by inflammation of mucus membranes, oral and nasal cavities, tracheae, and bronchial tubes. It may progress to severe pulmonary symptoms. Longer-term exposures to lower concentrations may result in the development of chronic berylliosis. This form of the disease is highly variable in onset and is more likely to be fatal. Chronic berylliosis primarily affects the pulmonary system and is characterized by the development of scar tissue that stiffens the lungs and can eventually make breathing impossible. For subchronic exposures to beryllium, some studies suggest that the human health consequence may be cancer.

There are other types of health effects caused by exposure to toxic substances. Local health effects occur when a toxic substance has contact with the body—on the hand or eyes or in the lungs. If skin

is splashed with a strong acid, the resulting burn is a local health effect. A systematic effect takes place when the toxic substance enters the body and damages a specific physiological or neurological function—liver, kidneys, or bone marrow. Chronic exposures to low levels of arsenic cause hematological (blood-related) systematic damage to veins and arteries, increased blood pressure, and severe anemia. Synergistic effects occur when the body is exposed to two or more toxic substances at the same time. The combined effect can be greater than the individual effects. For example, most smokers face a one in 10 to one in 20 chance of developing lung cancer. This risk, however, increases 50–90 times if a smoker is also exposed to asbestos. Nonsmokers have a one in 200 chance of developing lung cancer.

Each of the effects described (acute, chronic, local, etc.) can be related to a specific toxic substance (asbestos, arsenic, etc.). The following table provides a list of common environmental contaminants and their toxic effects on the body. These health effects can be more broadly classified into two main types of categories: those that cause cancer (carcinogenic) and those that have other health effects (noncarcinogenic).

## CARCINOGENIC HEALTH EFFECTS

*Cancer* is the term used to describe a group of diseases that form fast-growing and usually fatal accumulations of abnormal cells called neoplasms. The unstructured mass resulting from the neoplasm's development is a tumor, which does not obey or follow the biological control mechanisms that govern the growth and function of an organism's cells. Tumors simply grow for the sake of growing and provide no biological service or value for the host organism.

Tumors can be classified as either benign or malignant. Benign tumors grow more slowly than malignant ones, and the tissue of a benign tumor is structured in a manner similar to that of the tissue from which it is derived. The tissue of a malignant tumor, however, has an abnormal and unstructured appearance. The most important distinguishing feature between benign and malignant tumors is that benign tumors do not metastasize. That is, benign tumors do not spread or begin to grow in places other than their point of origin. *Cancer* is a term used to describe a malignant neoplasm or tumor that is moving or has moved beyond its point of origin. *Tumor* is used to denote a mass of neoplasm that is readily distinguishable and confined in the surrounding, normal living tissue.



### SOURCES AND HEALTH EFFECTS FROM EXPOSURE TO ENVIRONMENTAL CONTAMINANTS

Category	Name	Health Effect	Sources
Metals	Arsenic	Skin damage and circulatory problems; increased risk of cancer	Semiconductor manufacturing, petroleum refining, wood preservatives, erosion of natural deposits
	Beryllium	Intestinal lesions	Discharges from metal refineries, coal processing plants, and electrical/aerospace industries
	Cadmium	Kidney damage	Corrosion of galvanized pipes, discharges from metal refineries, and erosion of natural deposits
	Lead	Developmental effects (brain damage) in infants and children	Corrosion of household plumbing fixtures and erosion of natural deposits
	Mercury	Kidney damage	Discharges from refineries and factories where mercury is used; runoff from landfills and erosion of natural deposits
Volatile organic compounds	Benzene	Anemia with decrease in blood platelets; increased risk of cancer	Discharges from factories where organic chemicals are used; leaching from waste disposal sites
	Ethylbenzene	Liver or kidney damage	Discharges from petroleum refineries
	Tetrachloroethene	Liver damage; increased risk of cancer	Discharges from industrial facilities and dry cleaners that use solvents
	Toluene	Nervous system, kidney, and liver damage	Discharges from petroleum refineries
	Trichloroethene	Liver damage and increased risk of cancer	Discharges from industrial facilities that use solvents
Semivolatile organic compounds	Benzo(a)pyrene	Damage to reproductive systems and increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
	Di(2-ethylhexyl) phthalate	Damage to liver and reproductive systems; increased risk of cancer	Discharges from rubber and chemical factories

If exposure to a substance is known to produce cancer, it is classified as carcinogenic, or cancer-causing. The number of chemical substances or compounds that are known or proven human carcinogens is relatively small, fewer than 100. The list of suspected carcinogens, however, is much larger, about 300–5,000. Substances are evaluated for their potential to cause cancer in two ways: carcinogenesis bioassay studies and epidemiological studies.

Carcinogenesis bioassay is a type of toxicological study in which laboratory animals are exposed to high doses of the substance being evaluated. The

animals then are examined to see whether a malignant neoplasm (cancer) has developed. Exposure takes place over the course of the animal's lifetime (for rats, about 24–30 months). If a cancer develops, toxicological models can be used to predict or estimate the incidence of cancer that may occur when people are exposed to much lower doses of the substance that are more likely to be present in the environment or workplace.

Two categories of toxicological models are used to assess the potential carcinogenicity of substances. A nonthreshold, or one-hit, model assumes that

Category	Name	Health Effect	Sources
Semivolatile organic compounds (cond)	Pentachlorophenol	Damage to kidney or liver; increased risk of cancer	Discharges from wood preserving facilities
	Naphthalene	Anemia, kidney damage, and, in infants, brain damage	Burning of coal and oil, discharges from coal tar production and wood preserving
	Chrysene	Skin damage and possible increased risk of cancer	Found in coal tar pitch used to join electrical parts, also in creosote, a chemical used to preserve wood
Pesticides and herbicides	Chlordane	Liver or central nervous system damage; increased risk of cancer	Residues of banned insecticide
	Dalapon	Kidney damage	Runoff from herbicide used on road rights-of-way
	Heptachlor	Liver damage; increased risk of cancer	Residue of banned insecticide
	1,1-dibromo-3 chloro-propane (DBCP)	Damage to reproductive system; increased risk of cancer	Runoff or leaching from soil where it was used as a fumigant (disinfectant or pesticide) for such crops as soybeans and cotton
	2,4,5-TP Silvex	Liver damage	Residue of banned herbicide
Others	Nitrate	“Blue baby syndrome” in infants less than six months; asphyxiation as nitrate replaces oxygen-carrying hemoglobin in bloodstream	Runoff from fertilizer or leaching from septic tanks into water supply
	Polychlorinated biphenols (PCBs)	Immune, central nervous system, and reproductive damage; Increased risk of cancer	Burning of hydraulic oils and electrical insulating fluids; discharges from waste incinerators
	Radionuclides (uranium, radium, etc.)	Increased risk of cancer	Residues from mining and manufacturing operations; erosion of natural deposits
	Microorganisms ( <i>Giardia lamblia</i> , coliforms)	Gastroenteric disease (diarrhea, vomiting, etc.)	Human and animal fecal waste

very small quantities (the “one molecule” threshold) of a substance can result in cancer. The second type is called a threshold model and assumes that repeated exposures to a chemical are needed before a threshold dose, or minimal amount, is reached and cancer results. Most regulatory agencies generally use the more conservative nonthreshold models for carcinogenesis bioassays. These types of models assign a higher estimate of cancer potency to a chemical or substance than a threshold model. Threshold models often are used in the assessment of noncarcinogenic effects.

There are a number of agencies and research organizations that evaluate chemicals and other substances for their potential carcinogenic effects. Generally, a substance is considered carcinogenic if:

- It has been declared carcinogenic by the International Agency for Research on Cancer (IARC),
- It is listed in the Annual Report on Carcinogens published by the National Toxicology Program (NTP),

### VARIATION IN RATINGS BY DIFFERENT AGENCIES FOR SEVERAL SUBSTANCES

Substance	OSHA	IARC	NTP
Alcoholic beverages	—	1	1
Asbestos	1	1	1
Benzene	1	1	1
Coffee	—	2	—
1,2-Dibromo-3-chloropropane	1	2	2
Cadmium	1	1	1
Chlordane	—	3	—
DDT	—	2	2
Engine exhaust—gasoline	—	3	—
Lead and lead compounds (inorganic)	—	3	—
n-Nitrosodimethylamine (rocket fuel and industrial by-product chemical)	1	2	2
PCBs	—	2	2
Radon (and decay products)	—	1	1
Salted fish (Chinese style)	—	1	—
Solar radiation (sunlight)	—	1	—
Tetrachloroethene	—	2	2
Tobacco smoke and tobacco products	—	1	1
Welding fumes	—	2	—
Wood dust (certain hardwoods)	—	1	—

#### Key:

1: Known human carcinogen; 2: probable human carcinogen; 3: suspected human carcinogen; 4: unknown or unclassifiable human carcinogen; 5: Noncarcinogenic

— Not studied

OSHA: Occupational Safety and Health Administration, U.S. Department of Labor

IARC: United Nations International Agency for Research on Cancer

NTP: National Toxicology Program, U.S. Department of Health and Human Services, Public Health Service

- It is regulated as a carcinogen by the Occupational Safety and Health Administration (OSHA), or
- It is regulated by USEPA as a human carcinogen.

The classification schemes for each of these agencies contain five basic categories:

- The substance is known to cause cancer in people (known human carcinogen).
- The substance is likely to be carcinogenic (probable human carcinogen).
- The substance may cause cancer (suspected human carcinogen).
- Not enough information is available as to whether the substance is carcinogenic (unknown or unclassifiable human carcinogen).
- The substance probably does not cause cancer (noncarcinogenic).

Each classification carries its own set of requirements, and the descriptors are used carefully by researchers and regulatory agencies to describe the substance. Each of these agencies or organizations has its own standards and research practices, so not all substances are classified the same way. The following table provides an example of some substances that EPA considers carcinogenic, and the NTP, IARC, and OSHA do not.

However, for most common environmental contaminants (benzene from petroleum hydrocarbons, for example) there is general agreement as to carcinogenic classification.

See also ARSENIC; ASBESTOS; BERYLLIUM; CYANIDE; ENVIRONMENTAL PROTECTION AGENCY (EPA), U.S.; INORGANIC POLLUTANTS; MERCURY; ORGANIC POLLUTANTS; PESTICIDES; TOBACCO SMOKE; VOLATILE ORGANIC COMPOUND.

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# U

**underground storage tank (UST)** An underground storage tank is a metal or fiberglass tank used for bulk storage of liquids under the ground surface. USTs are used for gasoline, heating oil, and liquid chemicals such as benzene, methyl tert-butylether (MTBE), xylene, ethylbenzene, and other volatile organic compounds (VOCs). Among the main sources of residential point source pollution are leaky underground storage tanks. Buried commercial and home heating fuel tanks, as well as retail gasoline tanks, have historically been made of steel. With groundwater acting on the exterior of these tanks and long-term accumulations of water from the fuel on the bottom of the tank (water is denser than fuel), over time, rust produces leaks in the bottom of the tanks. Fuel constantly leaks from the tank at different rates throughout the year (faster rates when it is full) and infiltrates the soil. It percolates through the soil and settles on the surface of the water table, where it floats and accumulates. Depending upon the movement of groundwater, the spilled fuel may either accumulate underneath the tank or move in a plume away from the tank. Either way, both the soil and groundwater become polluted by the leak. In some cases, the plume may reach other houses, where odors may enter the indoor air through the basement. The plume may also enter surface waters if the groundwater intersects a stream, spring, or lake and be spread even farther.

## **TREATMENT OF A LEAKY UST**

The first step in the treatment of a fuel oil leak is delineation of its extent. Samples of soil around the tank are collected using an auger or drill rig and analyzed for heating fuel content. If the leak

has entered the water table, groundwater samples must also be collected and analyzed. Test wells must be drilled around the tank to determine the aerial extent of the plume, as well as the concentration of product or pollutant within the plume. Environmental consulting companies perform these services and must be licensed by the state and local regulatory agencies to perform such work. Ultimately, a map of the plume of pollution that shows both extent and distribution of pollutant concentrations is produced.

## **Residential Tanks**

Remediation of the spill may take on a number of forms depending upon the severity and the extent of affected area. In any event, the tank (UST) must be removed from the ground and disposed of (termed tank pull). For small leaks, some of the soil beneath the ground may require removal but no other procedures. In cases of strong impact on the water table, recovery wells are installed and the fuel oil is removed by pumping. In other cases, soil may be removed and carted away or washed on-site and returned as fill. At times, air may be pumped into the soil, and the fuel is evaporated, or bacteria may be introduced for bioremediation. The method of remediation depends upon the depth of the water table; the distance to surface water and producing water wells; the character of the soil, sediment, or bedrock containing the plume; and the character of the homes and buildings in the area and their distance from the plume.

Even if residential USTs are sound, if the fuel system is changed to gas or electric or if a new tank is installed inside the house, the UST should be removed or treated. If the old tank rusts, it may collapse beneath a person's weight, posing a hazard

or even just collapse on its own, producing a sink-hole. Removal and fill of the hole can be performed relatively cheaply without involvement of regulatory agencies in most states. Treatment usually involves complete drainage and cleaning of the UST followed by filling with sand.

### Gasoline Tanks

Home heating oil tanks are not the only USTs of concern. In gas stations, underground tanks contain the fuel that is pumped into vehicles. They may also leak, creating much larger and more dangerous plumes than from residential tanks. Pipes from the tank to the filler or to the pump may also leak, creating other outlets for spills. Because so much product is involved with gasoline tank leaks and because gasoline flows more easily and may contain harmful additives, remediation of these problems is much more complicated and may require monitoring for long periods after the main cleanup. Pollution from leaking gas station tanks is commonly the environmental problem of greatest concern in residential towns with no major industry. It can affect large parts of communities and produce huge and expensive lawsuits. Leaking USTs from industrial plants are even more of a threat and can cause even greater damage. If other stored pollutants are denser than

water, they may sink through the groundwater system and require much more work for remediation.

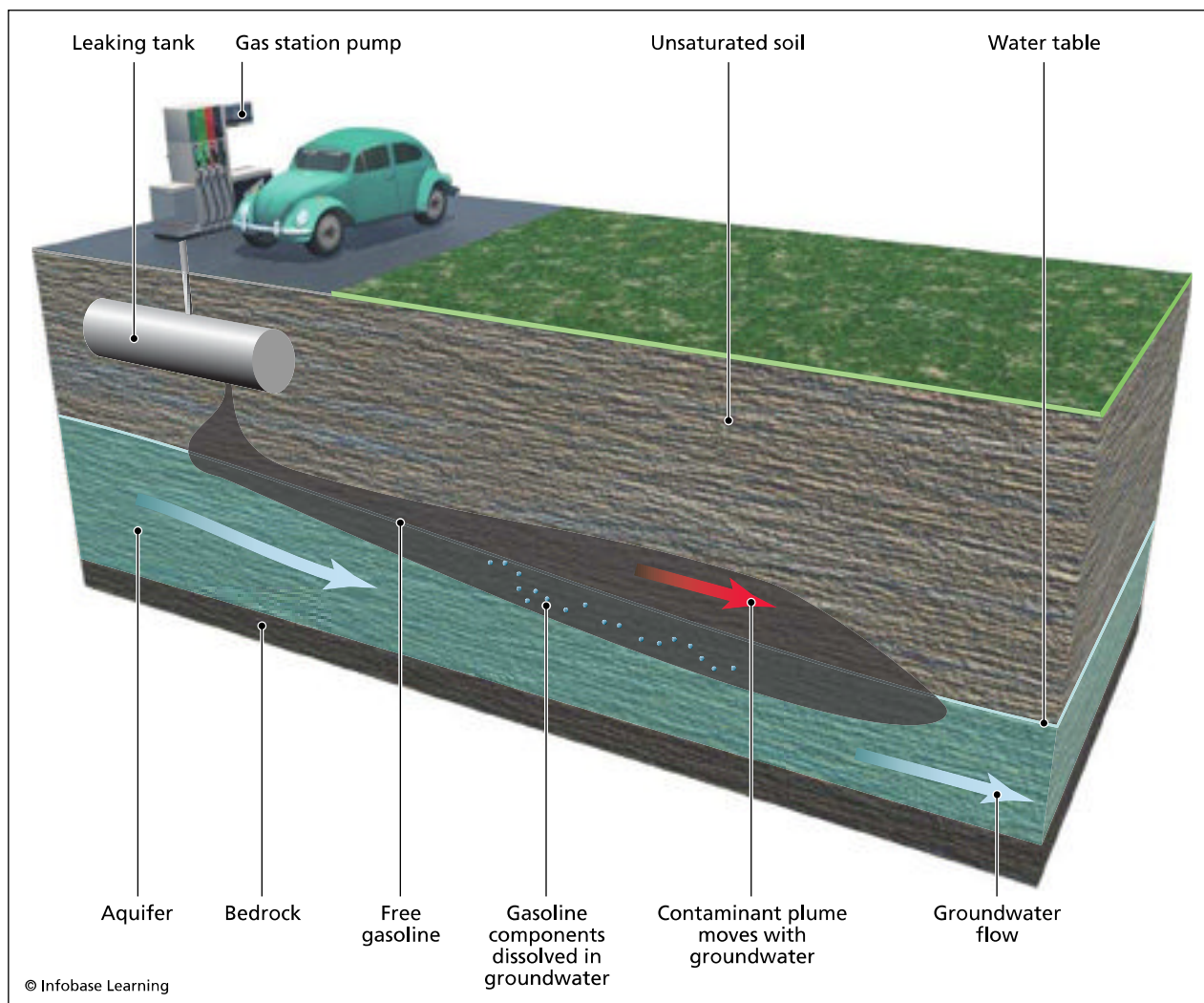
The federal government and most state environmental agencies have adopted regulations requiring the upgrades or replacement of these USTs since 1988. Several of these upgrades include secondary containment of both the UST and the accompanying piping; alarm systems, which detect a leak in the annular space between the double walls of secondary containment tanks; and several other methods, including manually using record keeping methods. These leak detection methods have minimized the potential for releases in both commercial heating oil and retail gasoline tanks. Typically, professionals must be licensed for tank closure in many states.

### Industrial Tanks

Heavy industry and the military also use USTs in some applications. Fuels and chemicals may be stored in very large steel tanks that are underground. These may be used at oil refineries in some cases, although most storage is handled in large circular aboveground tanks in these applications. Chemical plants commonly have some underground storage either for the raw materials or for the finished products depending upon the chemical. Currently, these tanks are well monitored and rarely leak, though the



Underground storage tank removal and replacement at a gas station in Sacramento, California, 2003 (AP Images)



**Block diagram of a leaking underground storage tank (UST) for gasoline beneath a gas station and the plume of pollutant in the groundwater**

pipes that fill or drain them may leak on occasion. Military bases have similar uses for USTs, though they may also contain weapons or weapon components in some cases.

If a large UST leaks, it is a major incident. Old leaky industrial USTs wind up as Superfund sites in many cases. The procedure for addressing such a problem is similar to that for a gasoline tank: delineation followed by remediation. The scale of the project is much larger and more involved. It is also more expensive. Some chemicals may be dense nonaqueous-phase liquids (DNAPLs), which, unlike gasoline, sink through the groundwater system. Cleanup of these sites may require extensive removal of soil and a much more complicated remediation plan. In some cases, if the leaking chemicals are toxic or caustic, the project may be very big and require special handling. These are even more expensive.

See also BENZENE; ETHYLBENZENE; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; IN SITU GROUNDWATER REMEDIATION; MTBE; SUPERFUND SITES; VOLATILE ORGANIC COMPOUND; XYLENE.

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**United Chrome Products Corvallis, Oregon (1983–present) Soil and Water Pollution** The city of Corvallis, Oregon, is approximately 85 miles (186.8 km) south of Portland. The municipal airport is five miles (8 km) south of downtown and was a military base until it was turned over to the city shortly after the end of World War II. Corvallis developed the airport into a fully self-sustaining entity through revenues from landing fees, hangar rentals, and even sales of grass seed from unused adjoining land. One of the main reasons for its success is the industrial and commercial development that has taken place around the airport. The city of Corvallis owns much of the land and leases it to a variety of private companies. This arrangement creates jobs for the community and provides revenues to the city from land and building rental fees. There are, however, risks associated with being a landlord, especially when one of the tenants is in the chrome electroplating business.

### BACKGROUND

*Chrome* is short for *chromium*, a metal that is used as a coating to add a bright, durable finish to a metal product. This coating can range from 10  $\mu\text{m}$  thick for decorative objects, sometimes called nickel-chrome, such as chair frames or motorcycle handlebars, to coatings up to 1,000  $\mu\text{m}$  thick, described as hard chrome, or engineered chrome, for industrial, wear-resistant applications such as motor valves or pump impellers. Engineered chrome usually is applied to hardened steel products and does not have a reflective finish.

The object to be plated in chrome is first polished, buffed, washed, and finally rinsed with a dilute acid to remove any residual oil or dirt. It is then dipped into a solution of nickel dissolved in hot sulfuric acid at 113–140°F (45–60°C), and an electrical current of 1.5–3 kiloamps per square yard (1.3–2.5  $\text{kA}/\text{m}^2$ ) is passed through the solution. The current causes the nickel to bond to the object. It is this first coating of nickel that provides most of the corrosion protection and metallic sheen for which chrome is famous. The entire process is repeated, and in the last step, the object is dipped into a bath of liquid hexavalent chromium ( $\text{Cr}^{6+}$ ). The chrome imparts a bluish hue or brightness to the item, prevents the nickel from tarnishing, and protects against scratching. Once plating is com-

pleted, the object is dried and rinsed to remove residual acids.

Electroplating is not an environmentally friendly process. Large amounts of spent acid and rinse water containing dissolved hexavalent chromium, nickel, and other toxic metals are generated. The proper disposal of this waste material represents a significant logistical and financial challenge for most electroplating companies, which tend to be relatively small operations. When the U.S. Environmental Protection Agency (EPA) began to develop the nation's hazardous waste management policy, electroplating residues were among the first industrial wastes for which they issued regulations.

### POLLUTION OF THE SITE

In 1956, United Chrome Products (UCP) moved onto a 2.5-acre (1-ha) parcel of land owned by the city of Corvallis in the Airport Industrial Research Park. For the next 19 years, UCP engaged in electroplating operations for a variety of commercial and industrial clients. UCP disposed of its spent plating bath solutions, stripping and cleaning bath solutions, and sludge from the bottom of plating baths by either dumping them into a dry well or storing them in the plating tanks.

The dry well was a three-foot (1-m-) deep pit outside the building and was backfilled with sand and gravel. It was connected to a sump within the building that drained spilled liquids, floor wash water, and product rinsate. Although UCP treated these wastewaters to neutralize the pH, they still contained significant concentrations of dissolved metals. Plating tanks leaked and discharged their contents, and these liquids infiltrated the building's floor and concentrated in soil underneath and adjacent to the structure. The amount of wastewater that flowed into the sump and then to the drywell, or that leaked from the plating tanks, is not known. Facility operators estimated that it was probably about 1,000 gallons (3,785 L) per year. Reportedly, the use of the sump and dry well was discontinued in 1975.

As regulatory pressure on the electroplating industry grew, facilities like UCP were inspected and required to account for their handling of wastes. At the beginning of 1983, the Oregon Department of Environmental Quality (ODEQ) sampled soil and surface water runoff at the UCP site as well as sediment and surface water in the Booneville Slough, a nearby tributary of the Willamette River. Elevated levels of chromium and other metals were detected, and, in July 1983, ODEQ issued a notice of violation to UCP for unlawful disposal of hazardous wastes and the discharge of hazardous wastes into public



waters. Chromium had migrated into the sediment and surface water of Booneville Slough by overland flow across contaminated site soils and via groundwater seepage from the dry well. Other studies showed that surface water contamination extended some two miles (3.2 km) downstream of the facility, and sediments were also affected along a 1.5-mile (2.4-km) stretch of Booneville Slough.

Later that year, the EPA announced that it had completed a groundwater investigation at the UCP site and found that significant levels of chromium were present in both shallow and deep groundwater underlying the property. Area residents tap the deep aquifer for drinking water. Potable water for the airport and associated industrial park is provided by two deep production wells operated by the city, about 3,000 feet (914.4 km) northeast and downgradient of the UCP site.

Chromium concentrations detected in shallow groundwater ranged from a few hundred parts per million (ppm) to more than 1 percent. In the deeper aquifer, chromium levels generally were 10 times lower, but still well above the drinking water quality standard of 0.05 ppm. The EPA estimated that more than 2 million gallons (7.6 million L) of groundwater had been contaminated as a result of UCP's waste management practices. Some 40,000 people resided within a three-mile (4.8-km) radius of UCP, and the nearest families lived approximately 900 feet (274 m) northeast of the facility.

UCP tried to respond to some of the requirements placed on it by both EPA and ODEQ. They emptied sludge from the plating tanks and stored it in drums, eventually disposing of some of them at an approved off-site facility. UCP retained a consultant to develop new waste management procedures and to design upgrades to its plating waste containment system. The environmental actions and required equipment upgrades, however, were too much of a financial burden for the company, and, in November 1984, UCP announced that it would cease operations in early 1985. By May of that year, its surplus equipment had been auctioned off and the building was vacated. Although it had not declared bankruptcy, the owners and operators of UCP simply abandoned the environmental mess they had created over more than 30 years of operation.

### THE CLEANUP

UCP was added to the National Priorities List as a Superfund site on September 21, 1984, and the EPA took immediate steps to stabilize the site. Some 6,300 gallons (23,846 L) of spent plating solution was removed from the site, and more than 100

drums of sludge were shipped to an off-site disposal facility. A chain-link fence was installed to reduce the likelihood of vandalism, and a drainage ditch was rerouted to prevent the flow of contaminated water into nearby surface water channels.

Even after these interim actions were completed, large amounts of chromium remained in on-site soil and dissolved in the groundwater. The EPA and ODEQ turned their attention to the city of Corvallis, the owners of the property, as the entity now responsible for completing the cleanup of the site.

By 1986, the EPA had developed a long-term remedial solution for the site, which was primarily the installation of a groundwater recovery and treatment system. In addition, the building was to be demolished and soil containing elevated levels of chromium that were acting as a continuing source of groundwater contamination was to be excavated for off-site disposal. By 1988, these actions had been completed and levels of chromium in groundwater began to decrease significantly. In 1992, the city of Corvallis assumed responsibility for the operation of the groundwater recovery and treatment system and agreed to reimburse the EPA for some of the costs associated with site cleanup.

Two additional areas of elevated chromium were discovered in 1998, and the city removed almost 2,000 tons (1,814 metric tons) of contaminated soil in 2000 and disposed of it off-site. Groundwater monitoring is ongoing, and chromium levels continue to drop in the shallow aquifer.

Every five years, the EPA evaluates the effectiveness of the work it has completed at the nation's active Superfund sites. These reviews are done to ensure that cleanup objectives are being met and that human health and the environment are protected as the remedial plans are implemented. The review of UCP verified that the cleanup is being successfully executed and is generally on schedule, although yet another small area of chromium-contaminated soil that will need to be addressed has been discovered between two monitoring wells on the site. The city of Corvallis has included the UCP property in the airport's master plan, and the site is being considered for redevelopment as a fuel storage depot.

*See also* AQUIFER; CHROMIUM; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; IN SITU GROUNDWATER REMEDIATION; NICKEL; SOIL POLLUTION; SUPERFUND SITES.

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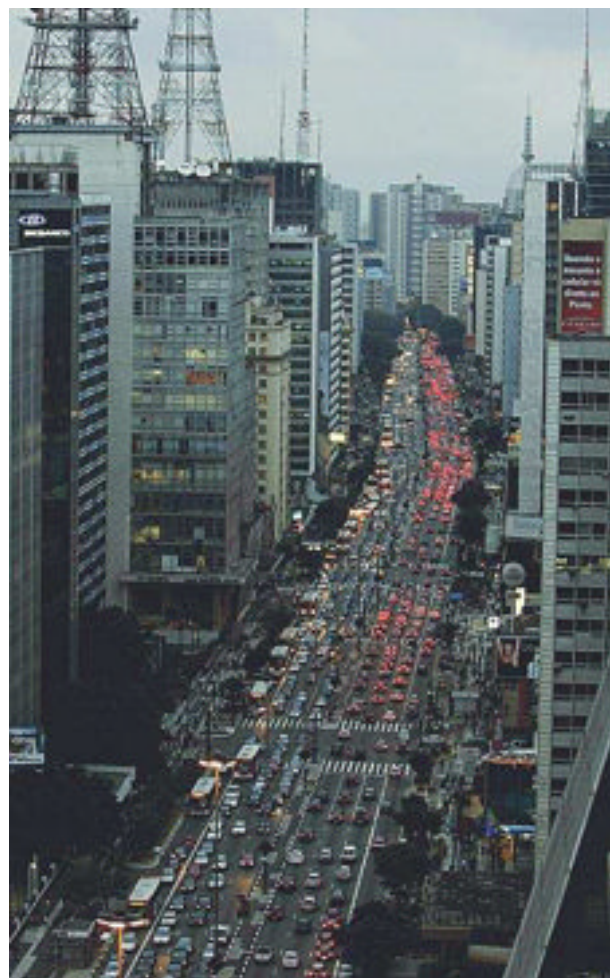
**urban air pollution** Beginning around 5000 B.C.E., agricultural techniques became sophisticated enough for farmers to produce more food than they needed. This new era heralded a set of far-reaching changes to human culture, allowing the development of mercantile, ruling, and military classes. Not everyone needed to tend crops or hunt to survive. These changes led to the domestication of animals, storage of surplus food, and concentration of populations in central locations or cities (from the Latin root *civis*, meaning "citizen") to trade and have access to the food. The formation of cities also spurred the development of educational and philosophical systems, medicine and technology, and political processes. People with many backgrounds joined to share ideas and skills and then take them to other areas.

Although human activities have always affected their environment, these changes could be accommodated when populations were small and widely dispersed. Tribes or family groups of up to a few hundred people living in semipermanent seasonal settlements or campsites may have overexploited nearby plants and animals through intensive hunter-gatherer activities, but local ecologies rebounded fairly quickly when the humans moved on.

As populations amassed in cities, however, the air, water, and soil they depended upon began to deteriorate. By about 10,000 years ago, scientists estimate that the Earth's population was between 1 million and 10 million people. By 1 C.E., the world population had grown to between 140 million and 170 million people, and ecosystems were struggling to compensate for the increasingly aggressive use of natural resources. In ancient Rome (100 C.E.),

which had an estimated population of more than 1 million permanent residents, prominent politicians and poets (e.g., Seneca and Horace) regularly complained about the foul smell and color of the city's air, naming it *gravioris caeli* (heavy heaven) or *infamis aer* (infamous air). Trash, sewage, and industrial wastes from mineral processing or leather tanning regularly fouled Rome's local streams and drinking water supplies. In medieval England, when the queen arrived in Nottingham in 1257, the smoke from coal burning had so polluted the air that, afraid for her health, she left after only a brief visit. Air quality in London eventually became so intolerable that King Edward I tried to ban the burning of coal threatening, "whosoever shall be found guilty of burning coal shall suffer the loss of his head"—and this was 500 years before the Industrial Revolution!

Today, as the result of modern technology and effectively enforced environmental regulations, most



**A 108-mile- (173-km-) long traffic jam in São Paulo, Brazil, 2006 (Vanderlei Almeida/AFP/Getty Images)**

## TOP 25 MEGACITIES RANKED BY TOTAL POPULATION

No.	Megacity (including surrounding metropolitan areas)	Population (millions)	Location
1.	Tokyo	34.3	Japan
2	Guangzhou	24.2	China
3	Seoul	24.2	South Korea
4	Mexico City	23.4	Mexico
5	Delhi	23.2	India
6	Mumbai (formerly Bombay)	22.8	India
7	New York City	22.2	United States
8	Sao Paulo	20.9	Brazil
9	Manila	19.6	Philippines
10	Shanghai	18.4	China
11	Los Angeles, California	18.0	United States
12	Osaka	16.8	Japan
13	Kolkata (formerly Calcutta)	16.3	India
14	Karachi	16.2	Pakistan
15	Jakarta	15.4	Indonesia
16	Cairo	15.2	Egypt
17	Moscow	13.6	Russia
18	Beijing	13.5	China
19	Dhaka	13.4	Bangladesh
20	Buenos Aires	13.3	Argentina
21	Istanbul	12.8	Turkey
22	Tehran	12.7	Iran
23	Rio de Janeiro	12.6	Brazil
24	London	12.4	United Kingdom
25	Lagos	11.8	Nigeria

Source: "The Principal Agglomerations of the World," by Thomas Brinkhoff, January 2010. Available online. URL: <http://www.citypopulation.de/world/Agglomerations.html>. Accessed September 21, 2010.

people living in the United States and other developed countries can breathe the air without fear. This, however, is not true for millions of people living in many cities in other parts of the world. The poor air quality in those cities is tied directly to the size of the population, the rate and type of economic development taking place, and, to a lesser extent, local geography and climate.

### MEGACITIES AND ENVIRONMENTAL QUALITY

There are many social, cultural, and economic advantages to cities, but above a certain size, they become very difficult to sustain ecologically. The industrial and commercial activities that take place in a city, as well as the people who live there, consume enormous amounts of resources. In addition, the wastes from the processing and consumption of

these resources must be removed and managed in a way that does not foul the environment. Infrastructures and systems have been developed over time that generally are effective in making most cities, for the majority of people in developed countries, reasonably pleasant and healthy places to live. Clean water is piped directly to homes, garbage is removed regularly, subways and buses reduce traffic congestion, and industrial polluters are well regulated.

Developed countries are those that have a high Human Development Index (HDI). As defined by the United Nations, the HDI is a comparative measure of life quality, especially for children, in five major categories: poverty, education, literacy, child mortality rates, and life expectancy. A country with a high HDI almost always has a large per capita gross domestic product, a representative government, an open or free-market economy, and a strong anti-corruption culture. A country with an HDI of 0.8 or more is considered developed (e.g., United States and most of Western Europe), whereas those with HDIs between 0.5 and 0.8 are designated as “moderately developed” (some of the former Soviet Union Eastern Bloc states). Countries with an HDI below 0.5 are classified as “developing” (many African nations).

As cities become larger, especially in developing countries, much of the infrastructure needed to make them sustainable, or even livable, has not kept pace with their growth. This is readily apparent in the world’s megacities—those with more than 10 million people living at a density of at least 3,220 people per square mile (2,000 people/km<sup>2</sup>). The world’s first megacity was formed in 1950 and consisted of the New York City metropolitan area. By 2006, 23 megacities had developed, reflecting a trend away from rural life to urbanization not only in North America and Western Europe, but also in all the major countries of the world. The table on page 744 lists the megacities in the year 2007.

Metropolitan areas that are likely to become megacities by 2015 include Jakarta (Indonesia), Osaka (Japan), Tianjin (China), Bangkok (Thailand), and Manila (Philippines). Occupying less than 5 percent of the Earth’s surface, the existing megacities use more than 70 percent of the planet’s wood and 50 percent of the water and generate more than 80 percent of all anthropogenic atmospheric carbon. Thirty-six megacities are expected to have formed by 2025.

The overwhelming size of megacities often makes them difficult to manage in an environmentally effective manner, especially in terms of air pollution. Water contaminated by sanitary or industrial wastes can be contained, treated, and either recycled or discharged by using well-defined and controlled processes. Simi-

larly, solid wastes can be collected and disposed of in a manner that is reasonably efficient and fairly protective of public health. Air pollution, however, especially from nonpoint sources, is much more difficult to control because of its enormous volume, tendency to move quickly away from its point of origin (often across national boundaries), and the immediate effect that attempting to control or reduce it has on the general population of a megacity. One study by the United Nations found that in cities with populations of greater than 9 million people, health risks to children related to air pollution (asthma, bronchitis, etc.) are greater than if those same children live in less congested towns and villages.

It is tempting to point to megacities in developing countries as those with the worst air quality. Although it is true in many cases (as described in the case studies that follow), it is not universally applicable. New York, Paris, Tokyo, and Los Angeles have some of the highest nitric oxide levels (produced by automobile emissions) in the world. The main difference in air pollution found in developed versus developing countries is the reaction of both the government and population to bad air quality when it is detected and reported. In most developed countries, strict regulatory programs are established to reduce atmospheric contaminant loading and require the installation of pollution control equipment. This is often not the case in developing countries, or, if such requirements are in place, they may be enforced only selectively or sporadically.

## URBAN AIR QUALITY: CASE STUDIES

A review of air quality in the four urban areas describes the reasons for such poor conditions and tries to define the cultural and institutional challenges faced by each megacity in attempting to develop and implement sustainable air quality improvements. All the case studies are focused on megacities in developing countries because these often contain the largest populations that are being the most severely impacted.

### Mexico City, Mexico

Between 1970 and 2000, the Mexican economy grew more than 200 percent, resulting in better education, medical care, and social services for many of its citizens. In 2003, Mexico had a UN calculated HDI of 0.813, categorizing it as a developed country. Much of this growth has been centered in Mexico City, whose population increased from 9 million people in 1970 to more than 20 million by 2000. As Mexico’s capital and only megacity, Mexico City also has a reputation for having some of



the poorest air quality in the Western Hemisphere. Founded in the 1520s, Mexico City is in a large valley surrounded by volcanic peaks in the center of the country's *altiplano*, or "high plane," a plateau elevated about 7,500 feet (2.3 km) above sea level. This geography plays a crucial role in exacerbating air pollution in Mexico City. In 1940, average visibility in Mexico City was more than five miles (8 km). The snow-capped peaks of the surrounding volcanoes towered over the city and added a picturesque charm and majesty that were not found in many other capital cities. Today, visibility is often less than one mile (1.6 km), and the mountains to the east, south, and west are seldom seen. The mountains that surround the city prevent winds from helping to sweep away contaminants and help trap hydrocarbons and the by-products of fossil fuel combustion: particulate as well as sulfur and nitrogen oxides. Contributing to pollutant enrichment of Mexico City air quality are winter temperature inversions, when a layer of warmer air moves over, or caps, a layer of underlying colder air.

In 2001, Mexico was the 13th largest emitter of carbon dioxide (CO<sub>2</sub>) in the world, discharging about 106 million tons (96 million metric tons) of this greenhouse gas. Of all CO<sub>2</sub> emissions in Mexico, 13 percent were released in Mexico City. Particulate pollution (microscopic size pieces of soot and ash produced primarily by the combustion of diesel fuel) exceeds international air quality standards (i.e., safety level) almost once per week. Ground-level ozone concentrations, produced when sunlight interacts with nitrogen oxides and volatile organic compounds, are above international air quality standards 330 days of every year. Nitrogen oxides reach unhealthy levels about 180 days a year.

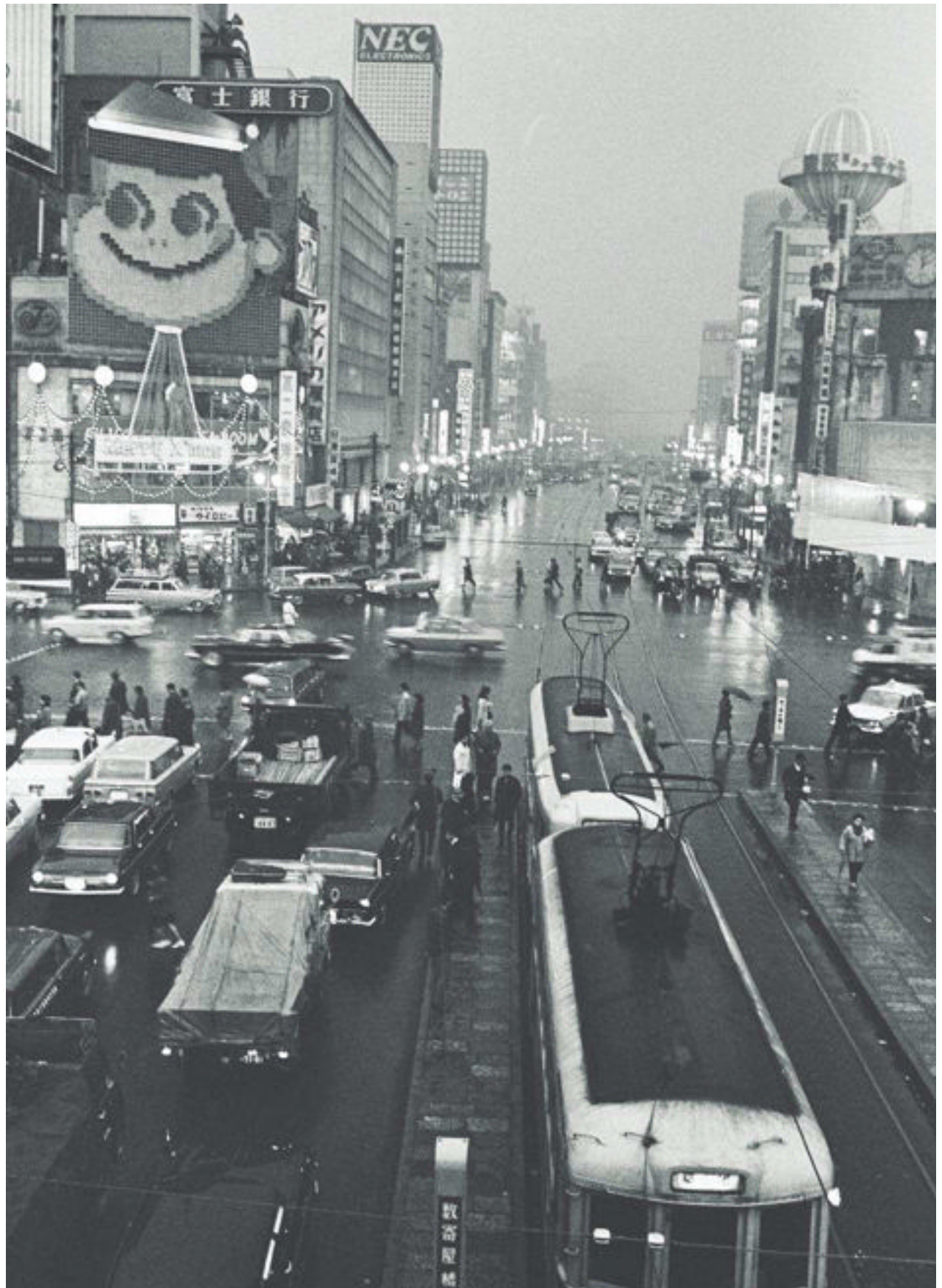
More than 80 percent of the air pollution within Mexico City is directly connected to automobile emissions. Mexico City has slightly fewer cars than Los Angeles (4 million v. 5.2 million), but they are older, do not have catalytic converters, are in poorer condition, and burn gasoline or diesel fuel less efficiently. They consume some 10 million gallons (37.9 million L) of fuel daily and use more polluting fuels (those with high sulfur levels). The four major pollutants present in Mexico City's air are ozone (O<sub>3</sub>), sulfur dioxide (SO<sub>2</sub>), nitrogen oxide (NO<sub>x</sub>), and carbon monoxide (CO). Each of these originates from the incomplete combustion of gasoline or diesel fuel. More than 36,000 factories also contribute to the often-unhealthy levels of these air pollutants.

Mexico City's air contains dried fecal matter present in sewage discharged into open air lagoons near the city as well as from the millions of stray dogs that roam the streets. Physicians practicing in Mexico City have documented cases of hepatitis, dysentery, and other gastrointestinal diseases that resulted from breathing airborne fecal matter. Every year 4,000 premature deaths that are attributed to air pollution occur in Mexico City, and 2.5 million days are lost from work.

Mexico's government is working hard to improve air quality not only in Mexico City, but also in the six other largest urban areas: Guadalajara, Mexicali, Monterrey, Tijuana-Rosario, Toluca, and Ciudad Juarez. Since 2000, Mexico has spent more than \$5 billion on technology initiatives and regulatory programs to try to clean the air in its capital. These have included the following:

- replacing municipal buses that ran on diesel fuel with hybrid motors (gasoline-electric or natural gas) and requiring the installation of particulate filters and high-efficiency catalytic converters on certain types of diesel engine vehicles
- requiring that owners of private cars either have a catalytic converter or refrain from driving one day per week. During air pollution emergency days, vehicles ending with either an odd or even license plate number (depending upon the day) are allowed on the road
- shutting a local oil refinery that could not meet stringent air emission standards now in effect for the city
- replanting trees and other vegetation on nearby hills and mountains that had been clear-cut years before

Tougher, more expensive, and politically sensitive reforms have proven difficult to implement and enforce. This problem may be related to the way oil and natural gas are managed in Mexico. In 1938, the assets of two foreign-owned oil companies, which had been developing Mexico's oil resources for more than 20 years, were nationalized by the Mexican government. The result, PEMEX or *Petróleos Mexicanos*, is the world's fourth largest oil exporter. PEMEX is the only company allowed to extract,



refine, and sell petroleum fuels in Mexico. Its current reserves, located primarily offshore in the deep waters of the Gulf of Mexico, are estimated by the company to be in excess of 200 million barrels (31.8 billion L). For comparison's sake, Kuwait estimates oil reserves of 100 billion barrels (1.59 trillion L). While seemingly small compared to the oil reserves in the Middle East, PEMEX's potential oil is very attractive because of its presence in relation to markets in the United States. Currently, PEMEX provides revenues that make up a third of the Mexican government's annual operating budget.

The key to reducing air pollution in Mexico City is controlling emissions from mobile sources. The Mexican government has provided incentives for its citizens and some businesses to retire older vehicles and replace them with cleaner, more fuel-efficient cars and trucks. The quality of the gasoline and diesel fuel that runs those vehicles plays a major role in citywide air quality. Very low-sulfur fuels, both gasoline and diesel, are needed to achieve real gains in Mexico City air quality. To remove the sulfur, PEMEX's nine refineries need expensive upgrades to their processing equipment, costing between \$2 billion and \$4 billion, which could significantly affect the company's revenue contribution to the government.

Although considered a developed country, Mexico is still struggling with balancing economic progress against environmental quality. The signs are favorable that a viable solution is forthcoming. Mexico's federal environmental agency, Secretaría del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP—Secretary of the Environment, Natural Resources, and Fishery), and Mexico City's local Secretariat of the Environment have established air quality standards that are just as strict as those of the United States. PEMEX has been working to produce low-sulfur fuel by 2008, and alternate sources of electricity, such as hydroelectricity, geothermal, solar, and wind, are being actively developed. In fact, Mexico is the third largest producer of geothermal power (almost 900 megawatts of capacity), ranking just behind the United States and the Philippines. This is reflected in its greenhouse gas emissions, which have remained fairly constant since the late 1990s.

Mexico City's air quality is improving, although it will be years before its residents can regularly breathe healthy air. With an increasing commitment to enforce existing laws, however, and continued development of innovative air pollution control systems and technologies and use of alternative energy sources, Mexico and Mexico City are on the verge of reversing years of disregard for the environment.

### Delhi, India

If Mexico City is beginning to emerge from its environmental dark ages, New Delhi, India, is at the beginning of its journey. India, a country that is rapidly becoming a global economic powerhouse, also has some of the most polluted cities in the world, and New Delhi is a microcosm of all the ecological challenges that this rapidly developing country faces.

The world's second most populous country after China, India (HDI = 0.602) hosts almost 17 percent of the planet's population (1.1 billion in 2001) on only about 2.5 percent of its surface area (135 million square miles [349.7 million km<sup>2</sup>], about one-third the size of the United States). In 1991, India began to implement a series of economic and political reforms that transformed the country. Import tariffs were reduced, foreign investment and ownership of local business encouraged, and government regulation or management of many industries (including telecommunications) ended. Since these reforms took effect, India has become one of the 10 fastest developing countries, with its gross domestic product increasing at an annual rate of 6 percent. With this newly earned prosperity, India's population growth has slowed, literacy rates have increased (to 54 percent in 2001), and a spirit of entrepreneurship is sweeping the country. Poverty rates dropped from 40 percent in 1994 to 25 percent in 2000. Environmental problems, particularly air pollution, combined with the government's inability to provide such basic services as clean water, health care, and education, serve as a drag on further development and prevent India from assuming a true leadership role in Asia.

If there is one place in India where economic prosperity is juxtaposed with poor environmental quality, it is in the country's capital city, Delhi. As India's third largest city—only Mumbai and Kolkata have more people—Delhi is actually made up of two cities: Old Delhi to the north, formerly the capital of Muslim India, and New Delhi to the south, declared capital of the country by the British in 1911.

A tributary of the Ganges Yamuna River makes up the eastern boundary of the 600-square-mile (1,554-km<sup>2</sup>-) Delhi metropolitan area and the Thar Desert lies to the west. Hot, flat-lying plains are to the south and a cooler, hilly region to the north and east. The average annual temperature is 77°F (25°C), and the climate is semiarid, with most of the rain (around 30 inches [78 cm]) falling during the monsoon season: June through October. These rains act as effective scrubbers, removing both suspended particulate from desert dust storms (called *Andhis*) as well as industrial air pollution. Pre- and post-



monsoon calms, combined with regular midwinter temperature inversions, lead to increased pollutant loading as contaminant concentrations build up in the stagnant air.

Two national laws codify the standards for air quality in India: the Air (Prevention and Control of Pollution) Act, passed in 1981, and the Environment (Protection) Act, promulgated in 1986 shortly after the Bhopal disaster. The standards established by these acts for lead, suspended particulate matter, SO<sub>x</sub>, and NO<sub>x</sub> are similar to those in the United States and the European Union. But the Central Pollution Control Board (India's equivalent of the U.S. Environmental Protection Agency [EPA]) does not have a good record of uniformly or vigorously enforcing these standards throughout the country.

The 20 million inhabitants of Delhi use almost 5 million vehicles to travel into, out of, and around the city. About two-thirds of these vehicles are small motorcycles or rickshaws powered with noisy two-stroke engines. These types of engines are small, lightweight, inexpensive, and powerful. In two-stroke engines, oil (for lubrication) is premixed with the gasoline, and unburned oily residues are pushed out the exhaust chamber along with the regular by-products of combustion (NO<sub>x</sub>, SO<sub>x</sub>, etc.). For all their advantages, two-stroke engines are environmentally unfriendly, emitting much more contamination than other types of internal combustion engines.

Delhi's system of old, twisting, and tortuous roads intermixed with more modern streets and highways creates low-speed driving conditions that result in poor engine performance and additional air pollution. Even though the city has expanded its mass transport facilities (primarily buses with coordinated rail service), enormous, long-lasting traffic jams are still commonplace.

Total suspended particulate matter (SPM) is Delhi's most obvious air pollution problem. SPM in Delhi's air annually averages 370–450 mcg/m<sup>3</sup>, well above the prescribed standard of 140–360 mcg/m<sup>3</sup> (depending upon local land use). SO<sub>x</sub> and NO<sub>x</sub> levels are slightly below national standards, but they have increased by almost 100 percent since the late 1990s, and this trend of deteriorating quality is likely to continue. Underlying these findings is a concern that Delhi's air quality data are not collected or analyzed consistently or in a scientifically appropriate manner, either because of poor training of the technicians or lack of funding for needed equipment. The human health consequences of this pollution are disturbing. Approximately 7,500 premature deaths and almost 3 million hospital admissions or severe illnesses that require medical treatment are attributed to exposure to air pollution.

Although cars and other motor vehicles are responsible for 67 percent of the 3,300 tons (2,994 metric tons) of pollutants that are emitted every day into the air over Delhi, the following other sources also are present:

*Coal-fired power plants (13 percent).* Over the last 25 years, India's rapidly growing population and increased rate of urbanization have resulted in the doubling of energy consumption. Even with this explosive growth, the country's per capita electrical use still is one of the lowest in the world. India (like the United States) is not a signatory to the Kyoto Protocol (the international agreement to reduce greenhouse gas emissions) and is the fifth largest emitter of CO<sub>2</sub> in the world. The rate of greenhouse gas discharges by Indian business and industry is expected to increase dramatically over the coming years.

The three power plants that provide electricity to Delhi are symptomatic of India's energy crisis. Operated using high-sulfur coal or peat fuels, these power plants emit more than 6,000 tons (5,443 metric tons) of fly ash into the air every day and have only recently installed electrostatic precipitators. In addition, the government is hesitant to enforce national limits on sulfur dioxide and nitrogen oxide emissions, because of the need for electricity to support the current rate of economic growth. Even when limits are established, they are often not locally enforced for that same reason.

*Industrial discharges (12 percent).* Delhi has been India's leading manufacturing and commercial center since the 1800s, specializing in arts and crafts, textiles and handlooms, as well as copper utensils. The air pollution from these and other types of industrial activities has been on the decline since the 1990s, when Delhi began to shift to a service-based economy. Since 1991, more than 1,300 industries that could not meet air pollution control requirements have closed, and this trend is continuing as the Indian government seeks to encourage development by less polluting, less energy-intensive businesses.

*Domestic sources (8 percent).* The primary sources of these emissions are cook stoves called *chulhas* that are fired with biomass fuels such as coal, dung, crop residues, wood, and charcoal. India has embarked on a campaign to encourage the use of natural gas-fired *chulhas*, as well as those that incorporate solar technology.

The residents of Delhi are far from resigned to living with dirty air. They have instituted a series of aggressive air pollution control measures:

- improving the quality of lube oil for small vehicles



- banning the use of leaded gasoline (resulting in a substantial drop in ambient air lead concentrations within the city)
- requiring the use of low-sulfur diesel fuel in buses and trucks
- aggressively checking for fuel adulteration at service stations
- launching a public antipollution campaign designed to encourage the use of mass transit and other air quality improvement measures
- mandatory retirement of vehicles older than 15 years
- gradually switching the entire public transportation system (taxis and buses) to natural gas-fueled engines

Nationally, India is aggressively pursuing alternate energy rather than building conventional fossil fuel- or nuclear-driven power plants. It is the only country that has a government ministry focused exclusively on the development of nonconventional energy sources. In India, solar power and wind power are being touted as the most effective ways to produce electricity for the 70 percent of the population that does not live in cities. Delhi, as have many of India's major cities, has begun to make some progress in its effort to balance economic growth by addressing air pollution and other quality-of-life issues such as health care and education. Its success will lie in developing and maintaining a strong commitment to the promotion (and enforcement, when necessary) of industrial and community compliance with existing environmental regulations.

### **Santiago, Chile**

Santiago, Chile's capital and largest city, started out as a tough industrial town and the manufacturing center of the country. Historically, the development and growth of the city were based primarily on the extraction and refining of copper. Chile, with an HDI of 0.854, is the world's largest producer of refined copper. In the mid-1980s, the industrial character of Santiago began to change, and it has evolved into one of South America's most important financial and commercial centers. This is due largely to the strong growth of the Chilean economy and the country's relative political stability. This growth has been accompanied by environmental problems, and Santiago, although not a megacity, has air quality

so degraded that it is regularly ranked among the world's 20 most polluted urban areas.

Over the past three decades, Santiago's population has more than tripled, growing to 6 million people, about half of the population of the country. It is the sixth largest city in South America and is expanding so fast that the government has instituted several programs to encourage relocation of businesses and people into suburbs and areas away from the central city.

Santiago lies in a beautiful valley of central Chile, between the towering, snow-capped Andes to the east and the lushly vegetated Cordillera de la Costa (mountains of the coast) to the west. The city has a climate characterized by wet winters—June through August, with an average rainfall of 10–13 inches (25–33 cm)—and relatively hot, dry summers—November through March with average temperatures above 90°F (32°C). Both its location in a narrow valley and its seasonal weather patterns—calm, dry summers and regular thermal inversions during the winter—contribute to Santiago's air pollution. The calm air of summer allows pollutants to accumulate over the city between the two mountain ranges, and the winter thermal inversions, despite the occasional rainfall's scrubbing effects, act as a meteorological lid or cover and retard the dispersal of contaminants.

Chile enacted several environmentally related legislative initiatives. In 1990, the National Commission for the Environment (CONOMA) was created to develop and implement national environmental plans. The Special Commission for Decontamination of the Metropolitan Region (CEDRM) also was formed to focus specifically on pollution in Santiago. Regional Environmental Commissions (COREMAs) work throughout the country to improve environmental conditions. Chile is a signatory to several major international environmental conventions.

In the 1990s, the Chilean government recognized that the use of natural gas would both reduce Santiago's air pollution and provide a reliable source of energy. Five pipelines were constructed to import this clean-burning fuel from Argentina and Bolivia for both power production as well as industrial and residential use. The results were almost immediate. Between 1990 and 2000, air pollution in Santiago decreased dramatically as factories and power plants converted to natural gas. The availability of natural gas for use in Chile, however, is dependent on political and economic conditions in Argentina and Bolivia. Coupled with reductions in supply, a pattern of decreasing rainfall and subsequent lower river water levels has forced many of Chile's hydroelectric and natural gas-fired power plants to switch to more

polluting petroleum or coal. The gains realized in the 1990s were lost and Santiago again faces an air pollution crisis, this time from two, more politically difficult to control sources: automobiles and metal refining.

Although Santiago has a fairly extensive and reliable mass transit system that includes five subway lines and a modern bus fleet, as in many urbanized areas, its citizens like the personal freedom and economic flexibility of owning a car. Approximately 1.6 million automobiles operate within Santiago, and they generate about 53 percent of its air pollution. Exhaust from motor vehicles, especially on days when there is little wind or during a temperature inversion, causes concentrations of ground level ozone, total suspended particulate (TSP), and NO<sub>x</sub> and SO<sub>x</sub> to reach dangerously high levels. TSP values are often more elevated as wind blows dust from the numerous unpaved roads that connect Santiago's impoverished suburbs to the city. Adding to the pollutant load are emissions from more than 6,500 industrial (fixed or nonpoint) sources.

Public health has been significantly affected by air pollution in Santiago, with impacts ranging from premature death to increased occurrence of chronic bronchitis, pneumonia, and asthma. Particulate concentrations measured during the winter (July and August) have reached 300 to 400 mcg/m<sup>3</sup>,

well above the World Health Organization guideline 60–90 mcg/m<sup>3</sup>. The table compares atmospheric particulate concentrations measured in Santiago in 1992 with those in other cities around the world.

The Chilean government identified and implemented several short-term solutions to mobile source pollutants:

- An air pollution alert system (based on TSP concentrations) has been developed to warn people of poor air quality. Actions range from suggestions that people avoid strenuous outdoor activity to mandatory school closings and factory shutdowns.
- Depending upon air quality conditions, a rotating schedule restricts the number of cars allowed on the streets, similar to Mexico's odd/even system. Using this system, the government can prevent up to 20 percent of vehicular traffic from operating within the city.
- Many of the city's buses and taxis have been converted to operate on natural gas or hybrid fuel (diesel/electric).

In addition to these changes, road systems are being improved to ease congestion, and the subway system is being expanded to serve outlying areas better. Santiago also requires the use of very low-sulfur diesel fuel and has implemented an aggressive street cleaning program. These changes are making a difference. In 2005, only four emergency air quality alerts and nine "preemergency" notices were issued, as compared to 23 alerts and 157 preemergency notices in 1999.

Even though agriculture, textiles, and leather products are important industries, copper mining and processing from the rich deposits in the Atacama Desert region, 800 miles (1,288 km) north of the city, are the mainstay of Chile's rapidly developing economy. Once the world's largest open-pit copper mine, Chuquicamata (named for the Native Indian people who had worked the copper deposits since pre-Hispanic time) produces about 30 percent of the world's copper—720,000 tons (653,173 metric tons) annually. Associated with the sulfide ores extracted at this and other mines in the area are such air pollutants as arsenic, SO<sub>x</sub> dioxide, and TSP. Most air quality effects of mining occur locally, and fortunately the mines are in a sparsely populated part of the country. Occasionally, weather patterns disperse these pollutants over wide areas. In 1990,

#### COMPARISON OF TOTAL SUSPENDED PARTICULATE (TSP) CONCENTRATIONS

City	Average TSP (mcg/m <sup>3</sup> )
Athens	180
Bangkok	220
Beijing	370
Kolkata	390
Los Angeles	45–115
Manila	120–250
Mexico City	100–500
Mumbai	140
New York	60
Santiago	210
São Paulo	50–85
Tehran	260
Tokyo	50

for example, Chuquicamata was forced to cease operation for a month because excess emissions from its smelter were contributing to air quality problems in Santiago. The numerous other mines operating within the Atacama mining district have similar air quality impacts, both locally and nationally.

Environmental effects of mining are being mitigated in a number of ways. As the government invites more foreign participation, those companies introduce a culture of more strict compliance with local environmental standards. In addition, Chile now requires an environmental impact statement (EIS) before mining operations can begin in an area. This EIS must describe how air, water, soil, and other natural resources will be protected or restored during and after the mining process.

Chile, as have many developing countries, exploited its natural resources in order to join the modern world. This was done without much thought to the environmental consequences of those activities. The challenge for Chile now is to strengthen and secure those economic gains while balancing the need to maintain a sustainable and livable environment for its citizens.

### Linfen City, Peoples Republic of China

China (HDI—0.76) has emerged as an industrial and manufacturing superpower, but this development is stressing its environment to the breaking point. China is the fourth largest country in the world by area, and its world-topping population, more than 1.2 billion people, coupled with a wide variety of plentiful natural resources and an entrepreneurially oriented government, drives an economic engine that is changing the world.

By virtue of its size, China is often easier to view as a continent, rather than a country. In the northern part (Inner Mongolia, Heilongjian Province), the climate is very cold, whereas in the middle and lower reaches of the Yellow River, temperatures moderate (warm summers and cool winters). In the south, climatic conditions range from subtropical (east of Qinghai-Tibet Plateau) to tropical (Guangdong and Yunnan Provinces). At higher elevations, such as the Qinghai-Tibet Region, plateau climatic conditions (hot, dry summers and cold, dry winters) prevail. China is not characterized or dominated by a single topography or landform. Steppes, deserts, and high mountain ranges, including the Himalaya, make up the major surface features in the western part of the China. Large river basins form much of the central interior, and in the east are plains and low hills.

Just as the climate and topography vary, so do China's people and cultures. Nine major ethnic

### CHINA'S TOP EXPORTS (\$ MILLION)

Commodity	\$ millions
Electrical machinery and equipment	55,500
Power generation equipment	52,960
Apparel (clothing)	23,500
Iron and steel	9,200
Furniture	7,800
Medical equipment and optics	7,100
Footwear	7,000
Mineral fuels and oils	6,500
Chemicals	6,200
Plastics	6,000

groups speak eight different languages and have religious practices rooted in Taoism, Buddhism, Christianity, Islam, and Falun Gong. China's industrial focus is equally varied. Its top 10 exports are summarized in the accompanying table.

China began to modernize its economy in 1978 and since then has seen, on average, an annual increase of 8 percent or more in its gross domestic product. The central government has attempted to remain faithful to its underlying communist ideology, but China has established economic and trade zones where Western style capitalism and investment are not only permitted, but actively encouraged. The political and social reforms needed to ensure accountability for environmental quality, however, have not kept pace with economic growth and liberalization policies.

Studies by both the World Bank and the World Health Organization have found that of the 10 most severely air polluted cities in the world (see the following table), six are in China. Linfen City, in Shanxi Province, holds the dubious honor of being the world's most polluted city.

Linfen is one of China's oldest settlements. Located in the southwest of Shanxi Province, about 300 miles (480 km) southwest of Beijing, Linfen is about 8,000 square miles (20,720 km<sup>2</sup>) and has a population of 4 million. For most of its history, Linfen has been an agricultural center, a food exporter especially famous for high-quality fruits. But more recently the city's economic focus has shifted to a new type of export—coal. China is the world's largest coal producer, and Shanxi Province in northern China has more than a third of the country's proven reserves.

Of the nearly 26,000 coal mines in China, 40 percent are in Shanxi Province. Coal production increased from 1.1 billion tons to 1.9 billion tons (1–1.7 billion metric tons) from 2000 to 2005, and the rate of mining is increasing. This strategic area produces 70 percent of China's energy, primarily from coal-fired power plants, and Linfen is at the center of this industry. Straddling the banks of the Fen River valley, Linfen has all of the physiographic characteristics to make it susceptible to air pollution: high valley walls that reduce air mass mixing and a semidry monsoon climate with hot, calm, and dry summers leading to winters dominated by temperature inversions accompanied by the occasional heavy rainfall.

Major air pollution sources are of three types: electrical power generation (60 percent); iron, steel, and mineral production (30 percent); and other sources such as textiles, cement, and households (10 percent). Pollutants are primarily particulates (dust and soot) along with the by-products of combusted coal, the most serious of which is SO<sub>2</sub>. In 2000, air pollution sources in Linfen released about 75,000 tons (68,039 metric tons) of SO<sub>2</sub> and almost 200,000 tons (181,437 metric tons) of particulates from about 500 industrial sources. By 2002, these amounts had increased by approximately 30 percent. The highest pollutant concentrations in Linfen are found in winter, when stagnant air masses combine with high household use of coal to produce a visible haze that often slows traffic and makes outdoor activities unhealthy. Smoke generally blankets the city, and greenery in public streets and backyards is difficult to maintain because of damage from acid rain. Of the estimated 300,000 premature deaths in

China that are attributed annually to air pollution, 100,000 occur in Linfen.

The Chinese government is attempting to manage and control air pollution and environmental degradation in Linfen and other areas around the country. National environmental policies are developed by the State Environmental Protection Administration (SEPA) and approved by the State Council. Established in 1998, SEPA has the mission of promulgating and enforcing national environmental policy and regulations, collecting environmental quality data, and providing technological advice and guidance to policy makers on national and international environmental matters. One major initiative was the 2002 Cleaner Production Promotion Law. This law established special high-priority environmental remedial programs in 10 major cities and river valleys, including Linfen. China's basic air pollution control law—Prevention and Control of Air Pollution—was revised in 2002 to reduce emission limits and toughen penalties for noncompliance.

China faces an additional hurdle in its attempts to improve environmental quality that many developing countries do not. Environmental policies in many countries are formed at the grassroots level by the people whose health or quality of life is most affected by the pollutants being released. Through established political processes, constituent groups put pressure on their government for change. In China, where those types of public advocacy political processes are not well developed, environmental change is slow. While China may be modernizing, it steadfastly holds on to its Communist form of government, which, in turn, tends to make consistent and meaningful implementation of environmental reforms difficult.

*See also* AIR POLLUTION; CARBON DIOXIDE; FRONT; LOS ANGELES AIR QUALITY LEGISLATION; NEW YORK CITY, AIR QUALITY OF; NO<sub>x</sub>; OZONE; SULFUR DIOXIDE; TEMPERATURE INVERSION.

### THE WORLD'S 10 MOST POLLUTED CITIES (AIR QUALITY) IN 2006

1. Linfen, Shanxi Province
2. Yangquan, Shanxi Province
3. Datong, Shanxi Province
4. Shizuishan, Ningxia Hui Autonomous Region
5. Sanmanxia, Henan Province
6. Jincheng, Gansu Province
7. Shijiazhuang, Hebei Province
8. Xianyang, Shanxi Province
9. Zhuzhou, Hunan Province
10. Luoyang, Henan Province

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**Urquiola oil spill La Coruña, Spain (May 12–25, 1976)** *Water Pollution* Galicia is an autonomous region on the Iberian Peninsula along the west coast of Spain. It is the westernmost point of continental Europe, and its rugged coastline is known by mariners around the world as the Costa del Morte, or coast of death. The perilous jagged cliffs that reach into the sea, combined with fierce shoreward winds and strong currents, have had an average of three shipwrecks per year for at least the last 100 years. This is unfortunate, considering that Galicia also is on one of world's oldest and busiest shipping lanes. Vessels sailing to and from the Persian Gulf, India, and China make their way northward up the west coast of Africa and sail directly past Galicia on their way to ports in mainland Europe on a regular basis.

In contrast to its dangerous maritime reputation, the coastline of Galicia also is well known as one of the most scenic areas in Europe. Tourism is an important component of the region's economy, and the numerous coves and bays provide important wintering habitat for seabirds from throughout the North Atlantic including gannets, guillemots, cormorants, puffins, and gulls. Galicia's offshore waters are well oxygenated and nutrient-rich and support an abundant variety of fish, shellfish, whales, dolphins, and porpoises. As a result, the Galician fishing fleet is the largest in Europe.

### BACKGROUND

The *Urquiola*, a 905-foot- (276-m-) long, 128-foot- (39-m-) wide 59,723 DWT (deadweight tonnage) Panamax crude carrier, was placed into service in 1973. Flying a Spanish flag, the tanker carried oil from the Middle East to refineries in Spain, particularly to the government-operated facility in La Coruña, the second largest city in Galicia, northwestern Spain. La Coruña is one of the busiest ports on the Atlantic coast of Europe. It was the embarkation point for the Spanish Armada in 1588 as it set sail for England and was the site of a key battle between the French and English in the 1809 Napoleonic War. Today, the 260,000 people who live and work in and around its harbor and along its coastlines rely on fishing, farming, ship repairs, and the metal, glass, and ceramic industries for their economic livelihood. Tourism also

plays a major role in the local economy, as the area's picturesque harbor, rugged coastlines, and secluded bays and estuaries attract visitors from all over the world.

On May 12, 1976, the *Urquiola*, loaded with about 111,330 tons (101,000 metric tons [513,000 barrels]) of Kuwaiti crude oil, entered the main shipping channel to La Coruña harbor. This type of oil, also called Arabian light crude, is a medium-weight oil with an American Petroleum Industry (API) gravity of about 33 and a pour point of  $-30^{\circ}\text{F}$  ( $-34.4^{\circ}\text{C}$ ). The pour point of oil is the lowest temperature (in degrees Fahrenheit or degrees Celsius) at which it will flow or behave as a fluid. Oils with high pour points usually contain large amounts of paraffin and require more extensive refining to make them economically attractive. Pour points can range from  $0^{\circ}\text{F}$  ( $32^{\circ}\text{C}$ ) to below  $-70^{\circ}\text{F}$  ( $-57^{\circ}\text{C}$ ).

### THE ACCIDENT AND SPILL

At only three years old and with a good service record, the *Urquiola* approached La Coruña skippered by a Spanish captain in familiar waters. In the early morning light and on the way into the harbor, the tanker scraped its bow along a shoal that reportedly had not been marked on the ship's charts. Oil began to leak from the damaged vessel almost immediately, and, fearing a fire and explosion, as well as an environmental catastrophe, port officials ordered the vessel to be turned around and towed out to sea. As two tugs attempted to pull the *Urquiola* clear of the harbor, it grounded again, this time tearing a large gash in the bow storage tanks. Oil poured into the water, and *Urquiola* listed  $10^{\circ}$ . The smell of petroleum near the ship was almost overpowering.

The crew was ordered off the ship, but the captain stayed onboard to help coordinate salvage and lightering efforts. Two hours later, *Urquiola* exploded in a ball of flame and black smoke that set the sea on fire within several hundred yards of the ship. The captain was killed, and for the next 16 hours the burning oil, combined with an onshore breeze, spread a cloud of choking volatile gases over La Coruña and all areas within 62 miles (100 km) of the wreck. During the morning of May 14, a second explosion and fire blasted through *Urquiola*, and oil began to leak from the stricken vessel at the rate of 2,200 barrels (433 metric tons) per day. The *Urquiola* was not safe to approach for a week, but lightering began on May 21, and 50,000 barrels (9,844 metric tons) of crude oil was removed before bad weather halted off-loading on May 25. *Urquiola*'s stern section eventually broke apart in the heavy

seas with 10 to 15-foot (3–4.6-m) waves. The stern contained most of the sailing fuel, 22,000 barrels (3.5 million L) of Bunker C, and it was towed to a more protected area in the western part of the harbor for lightering. Unfortunately, a crack developed in one of the fuel storage tanks, and some oil was discharged into this previously unaffected area of the coastline. Overall, 100,000 tons (90,719 metric tons) of oil was discharged into the environment as a result of the *Urquiola*'s grounding.

### ENVIRONMENTAL AND ECONOMIC IMPACT

The response of the Spanish government included the immediate application of more than 2,000 tons (1,814 metric tons) of dispersant chemicals from 11 ships, both directly on the oil slick and along shorelines. Heavy seas and the lack of an official and documented spill response contingency plan limited the effectiveness of booms, skimmers, and other waterborne mechanical collection devices. By June 3, approximately 25,000 tons (22,680 metric tons) of oil had contaminated more than 130 miles (215 km) of coastline, 40 miles (64 km) of it described as "heavily" oiled. Onshore, a small contingent of about 100 workers using buckets and shovels, as well as 15 pieces of heavy equipment, attempted to remove the oil and froth from accessible shoreline areas.

This part of the Galician coast is characterized by submerged V-shaped valleys that form large embayments, locally called *rias*. The *rias* are protected from the full force of the Atlantic Ocean by steep, rocky headlands and a marsh-tidal flat system or by a small (less than 0.6 mile [1 km]) rocky or sandy coastline that can occur inside of them. As *Urquiola*'s oil was driven landward, its distribution within the three most impacted *rias* (Rias de la Coruña, Rias Area, and Rias Betanzos) was influenced by wave action, tidal stage, and the composition of beach material. Spring tides, those unusually high and low ocean levels that take place during the full moon, carried much of the oil ashore and distributed it across a wider area of beach face than it normally would have covered. This oil, which was deposited above the area of typical wave action, tended to be more persistent and difficult to clean up.

Oil making landfall in areas of intense wave action was buried deeper and more rapidly than those portions of the slick blown or carried into lower-wave-energy *rias*. On beaches made up of fine-grained sand, the oil coating the sediment was primarily superficial and penetrated less than 0.8 inch (2 cm) below the surface. This was because of the lower permeability and higher density of these

finer-grained and more compacted sediments, which greatly reduced the ability of the oil to migrate into the subsurface. In areas where the coastline was rocky, wave energy and lack of porous materials contributed to a faster natural cleaning and restoration, although initial effects on lichen and algae living on or attached to the rocks were often devastating. On coarse sand or mixed (coarse and fine sand) beaches, the oil penetrated deepest and was most difficult to remove. Wave action on these types of beaches tends to be more aggressive and sediments more porous and permeable, allowing oil to penetrate to depths of 12–24 inches (30–60 cm). The early, indiscriminant use of dispersants on shore may have contributed to the oil's ability to move deep below the surface in these areas.

Ecologically, more than 70 percent of the edible cockle, an important shellfish in this part of La Coruña, was killed off by either oil or dispersant. Populations of other shellfish species declined 10–30 percent and, because of their slow growth rates, required several years to recover to predisaster levels. Near-shore fishing for sardine and hake was banned, although deep sea fishing away from the wreck continued. The bird mortality rate was fairly low, with the majority of deaths in native gull species. Economic losses were estimated at approximately \$3 million and spill cleanup costs in the \$95-million range. The *Urquiola* was a Spanish-flagged ship on charter to the national oil company, and, as such, the Spanish government assumed responsibility for the spill and its aftermath.

See also BEACHES; CONTINENTAL SHELF; OIL SPILLS; TIDES; WAVES.

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**Usinsk oil spill Usinsk, Russia (October 1994) Soil Pollution** In 1982, the United Nations Convention on the Law of the Sea, an international agreement that resulted from the third United Nations Conference on the Law of the Sea, extended countries the exclusive rights to all natural resources on and underneath their continental shelves, up to 200 miles (322 km) from shore. The enormous submerged continental shelf off the northern, Arctic coastline of Russia became available as a result of this agreement. Along this northern continental shelf, which reaches into the Barents Sea and Arctic Ocean, under the frigid water and thousands of feet of silt and sand are some of the largest untapped deposits of oil and natural gas in the world. Estimates of the amount of potential hydrocarbons present in rocks that were deposited when Russia had a tropical climate indicate 90–100 billion tons (82–91 billion metric tons), with natural gas accounting for 80 percent of the volume. Oil- and gas-bearing areas may be present in more than 90 percent of the Russian continental shelves, about 2.3 million square miles (6 million km<sup>2</sup>). Discovered with only limited exploration, two very large oil and gas basins in the West Arctic on the shelves of the Barents and Kara Seas cover 0.8 million square miles (2 million km<sup>2</sup>) and contain potential resources of at least 50–60 billion tons (45.4–54.4 billion metric tons) of oil and natural gas.

This very large potential reserve of hydrocarbon, although present in remote and climatically extreme areas, represents not only energy security for Russia, but also a source of currency that, if managed properly, can be used to stabilize the economy and raise the standard of living for all of its citizens. The Russian government is eager to develop this important natural resource and the small city of Usinsk, just south of the Arctic Circle and 1,000 miles (1,609 km) from Moscow, is at the center of that effort. Winters there are long and cold, with only a 20-week-long mild spring/summer. This settlement of a few thousand oil field workers could become a major petroleum center. The Russian government

will have to decide to build a new, modern transcontinental pipeline to transport the oil and natural gas to Europe or to a yet-to-be-built terminal only a few miles to the north on the Arctic Ocean.

At present, however, the oil at Usinsk is pumped from the Kharyaga oil field of the Timan-Pechora Basin into a creaky 1972-vintage 29-inch- (73.7-cm-) diameter, 11.2-mile- (18-km-) long pipeline that connects with other pipelines. The oil is then sent to refineries operating in the more moderate climates of interior Russia. There are no facilities to capture and ship the methane recovered with this oil, and it is flared or burned. These giant flares, visible on satellite photographs from outer space, consume the same amount of natural gas that is used annually in Denver, Colorado.

### THE OIL SPILL

In October 1994, Usinsk became the site of one of the largest land-based oil spills on record, and it had devastating consequences for its local ecology. Four separate sections of the Usinsk pipeline had been leaking since February of that year, and the Russian oil company responsible for its repair and maintenance, KomiNeft, or Komi Oil, opted to capture the oil from these leaks and pump it to an area enclosed by an earthen berm or dam, rather than lose the revenue and incur the costs associated with stopping the flow of oil to make necessary repairs. This berm created a large oil lake or moat, holding more than 1.5 million barrels, or almost 60 million gallons (227 million L). Leakage from the KomiNeft pipeline has been linked to the practice of adding river water to the oil to help it flow. This water, however, tends to accelerate corrosion of the bare metal pipeline, especially near fittings and connections.



**Burning oil from the Usinsk pipeline spill, Siberia, December 1994 (Mark Warford)**

As the Russian winter began in earnest, the hastily constructed berm started to deteriorate from the alternating rain and snow with below-freezing temperatures. On October 1, a section of the berm collapsed and a torrent of oil was released into the ecologically fragile Siberian landscape. The oil flowed overland, making its way into local streams and drainage channels, and eventually covered more than 0.3 square mile (70 ha). Once released into the arctic climate of northern Russia, the oil was resistant to both evaporation and biological breakdown because of the low temperatures. In addition, the frozen ground slowed infiltration, and oil readily moved great distances over the landscape.

The Usinsk oil flooded into the Kova and Usa Rivers, which serve as important tributaries to the Pechora River, a major salmon fishery and habitat for many land-based species of plants and animals. The Pechora River flows into the Pechorskoye Sea, which gradually transitions into the Barents Sea.

### THE CLEANUP

At the time of the spill, KomiNeft was reportedly pumping about 4,000 tons (3,269 metric tons) of oil per day through the pipeline. This continued for several weeks after the spill began, until local officials were able to convince the company to shut down the pipeline temporarily to complete cleanup operations more effectively. Fortunately, the cold weather helped in oil containment and recovery, with cleanup consisting of bulldozers and other types of earth moving equipment used to scrape the layer of contaminated soil off the ground. This method, however, had the unfortunate side effect of destroying vegetation and other types of ground cover that had taken many years to become established in the short growing season of the inhospitable climate. As examples, trees take decades to grow a few feet and tire tracks in tundra grass remain visible for up to a half-century in this area. Workers simply set the oil afire if it was inaccessible in narrow stream channels, for example, or too difficult to remove. This practice further destroyed the fragile habitat. KomiNeft, the company responsible for the operation of the pipeline and cleanup of the spill, explained these tactics as necessary to prevent a more extensive disaster in the springtime, when warmer temperatures would make the oil more mobile.

This was not the first time oil was released from this pipeline. KomiNeft regularly tried to repair leaks and recover oil spilled from hundreds of discharges along the 11.2-mile (18-km) length of exposed and unprotected pipeline. Similar spills occurred in 1988, when more than 20,000 tons (18,144 metric

tons) of oil was released, and in 1992, when two pipeline breaks each released an estimated 30,000 tons (27,216 metric tons) of oil. International oil production experts estimated that Russia may lose as much as 20 percent of its produced oil from both pipeline leakage and theft of oil. The amount of oil released by the Usinsk spill is only exceeded by that intentionally discharged by the retreating Iraqi army in Kuwait at the end of first Persian Gulf War.

### FAR-REACHING EFFECTS

The 1994 spill and the spills that have occurred since then place at risk one of the largest herds of domestic and wild reindeer in Russia, estimated at 120,000 animals. For fodder, reindeer depend heavily on lichen, which grows as part of the ground cover throughout this region. If the lichen are damaged or destroyed by oil, the reindeer herds starve. The Barents Sea just north of Usinsk is a favorable habitat for one of the largest concentrations of white whales or beluga (of *Moby-Dick* fame) in the world. The beluga whale is known to swim upriver to feed on freshwater fish. This places it at an increased risk for damage from inland oil spills. Portions of the coastlines along the Pechorskoye and Barents Seas, which are major commercial fisheries, stay free of ice until mid-December and are essential breeding grounds for numerous types of seabirds and fish species.

The area where the spill took place is remote and not very populated. The initial release flooded approximately 0.3 square mile (70 ha) of tundra. Spring rains and floodwater pushed the oil across another eight square miles (2,100 ha), much of which was used as grazing land for reindeer herds. Some settlements and herders reported up to 90 percent of grazing and fodder-producing land was contaminated. The economic impact was estimated at \$103 million, and, with the cost of the lost oil and future cleanup added to the estimate, damages are almost \$500 billion. The U.S. Environmental Protection Agency (EPA) and Canadian environmentalists estimated that up to 220,462 tons (200,000 metric tons) of oil had been discharged; however, official Russian estimates are closer to 16,535 tons (15,000 metric tons).

### THE AFTERMATH

The Russian government fined KomiNeft the equivalent of \$600,000 for the 1994 spill and ordered them to begin cleanup operations immediately. The company was unable to pay most of the fine, however, because of a lack of financial resources. Instead, they gave local residents up to seven dollars each as



compensation for the ecological and environmental damage caused by the spill. Under pressure from the world community, Russia eventually agreed to allow foreign oil cleanup experts, a joint U.S.-Australian company, to assist KomiNeft in addressing the impacts of the spill. The European Bank for Reconstruction and Development loaned \$25 million for the cleanup operation, and the World Bank provided another \$100 million. Since the 1994 release, the oil containment berms around the leaking pipeline have been either rebuilt or reinforced, and work on improving pipeline integrity is ongoing.

In 1999, KomiNeft and its parent company, Komitek Oil Company, were purchased by LUKoil. Founded in western Siberia, LUKoil has developed into one of the major providers of oil and gas in Russia. The dissolution of KomiNeft represents only a part of the solution for the aging and inefficient Russian oil industry. Russia has only recently begun to allow the limited participation of outside oil companies in exploration and development projects as well as permitting them to improve and expand downstream refining and distribution systems. LUKoil has a reputation for aggressively pursuing joint venture opportunities with companies such as BP and Shell, and with these expanded business operations it is hoped that there will be a more sophisticated understanding and dedication to environmental protection.

*See also* CONTINENTAL SHELF; OIL SPILL; SOIL POLLUTION; WATER POLLUTION.

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# V

**Valley of the Drums Brooks, Kentucky (1967–2016)** *Water Pollution* Often cited as one of the reasons for the awakening of Al Gore's environmental consciousness, the A. L. Taylor site just outside Brooks, Kentucky, and only 125 miles (201.2 km) from the Tennessee border, played a key role in the passage of the Comprehensive Environmental Responsibility Compensation Liability Act, or CERCLA. The A. L. Taylor site was better known as the Valley of the Drums, and the startling and disturbing pictures from this site, combined with the disasters at Love Canal, New York, and Chemical Control Corporation, New Jersey, served to galvanize Congress and the nation into enacting some of the toughest waste control and environmental management programs in the world. It was in this way that, in 1975, the small town of Brooks, Kentucky, found itself at the center of the American environmental movement in its quest to address the cleanup of abandoned industrial waste sites.

## **POLLUTION OF THE SITE**

In 1966 and 1967, A. L. Taylor, a local landowner, decided to start a small drum recycling operation on his property. The property was typical of the north-central part of Bullitt County, with high walls with steep slopes on one side of a valley and lower, gentler slopes on the other. Mr. Taylor began by visiting local paint and coating industrial operations in nearby Louisville, Kentucky, and convinced them to send him their empty and partly full drums of solvents, paints, and chemicals. Taylor recycled these drums by emptying their contents into one of the five large pits he had dug on his 13-acre (5.3-ha) property, washing the drums out, with the rinsate

also going into the pit, and then either returning the drums to the customer or selling them as reconditioned containers. When the pits were full, Taylor simply set them on fire to burn off the residuals. Providing a much-needed service to his customers, A. L. Taylor was able to offer a very competitive price because he had not bothered to obtain the necessary permits to operate a waste disposal facility from the state of Kentucky.

The A. L. Taylor Drum Cleaning Service first attracted the attention of the Kentucky Department of Natural Resources and Environmental Protection Cabinet (KDNREPC) in 1967 after they received a report of a fire that had been burning for a week in one of the on-site waste pits. Despite being ordered to cease operations, Mr. Taylor continued to accept wastes and drums for on-site disposal and reprocessing, in direct defiance of aggressive legal action by KDNREPC. He agreed to stop burning wastes and eventually used soil from a nearby hillside to fill in and cover the pits. A. L. Taylor died in 1977. At that time, literally thousands of drums remained stored on the property, many of them full of liquid wastes and in poor condition.

Soil samples collected from around and within the waste pits and drum storage areas contained high concentrations of heavy metals, ketones, phthalates, polychlorinated biphenyls (PCBs), chlorinated alkanes and alkenes, aromatics, and polycyclic aromatic hydrocarbons (PAHs). Approximately 140 hazardous compounds were found to have been released to the environment at the site.

The main threat to public health and the environment was the physical presence of the waste materials in the Valley of the Drums, rather than its release into surface water or groundwater systems. Surface

runoff from the property entered a drainage ditch that flowed into Wilson Creek, a tributary of Pond Creek, which, in turn, empties into Salt River. The Salt River discharges into the Ohio River. The long pathway of more than 20 miles (32.2 km) for contaminants in the surface water to travel from the A. L. Taylor site to the Ohio River resulted in a dilution factor of greater than 1,000,000 to 1 before any drinking water intakes on the Ohio River were encountered.

The A. L. Taylor site is in the Knobs physiographic region of Kentucky, an area dominated by Middle to Late Paleozoic sedimentary rocks. Groundwater at the site occurs in two aquifers, a shallow unconfined soil aquifer and a deeper confined rock aquifer. Water table levels range from 2.4 feet (0.7 m) to 6.4 feet (2 m) below the surface. Shallow groundwater flows toward Wilson Creek. The topmost layer of rock in the area is impermeable shale, which tends to impede groundwater movement. The deep aquifer occurs in limestone under the confining shale and yields most of the water pumped from consolidated rocks in this area of the state. Water is contained in and moves along interconnected fractures and solution channels. Little local use is made of the shallow or deep aquifers, and no wells penetrate the deep aquifer near the A. L. Taylor site. Although fairly rural, the Valley of the Drums was bordered by a golf course and about a half-dozen private residences. These properties received their drinking water from cisterns or were connected to the Louisville municipal water supply system.

### NATIONAL ATTENTION ON THE PROBLEM

By 1979, KDNREPC realized they did not have the financial or technical resources needed to address the more than 17,000 partially full or empty drums present on the A. L. Taylor property. With no funding or administrative mechanisms yet available to address environmental effects of abandoned industrial wastes, the U.S. Environmental Protection Agency (EPA), founded only a few years earlier, in 1970, cleverly used their authority under Section 311 of the recently enacted Clean Water Act to allow federal funds to be used to construct interceptor trenches and a temporary granular activated carbon (GAC) water treatment system to prevent contaminated runoff from entering Wilson Creek.

During this time, the national media focused the country's attention on sites such as Valley of the Drums, and, on December 11, 1980, Congress passed and President Jimmy Carter signed CERCLA into law. One of the most important parts of this groundbreaking legislation was the development of the National Priorities List (NPL). This list served as

a compendium of the worst abandoned or inactive hazardous waste disposal sites in the United States. These sites were regarded as imminent dangers to public health or the environment. To provide money to clean up these sites, a tax was imposed on the petroleum and chemical industries, with those revenues going to a "Superfund," a large pool of dollars created to fund the cleanup of those types of facilities. Valley of the Drums was near the top of the first NPL list published by the EPA.

Another key component of CERCLA was the establishment of joint and several liability for those who caused or contributed to the contamination. Any business, company, or person whose activities resulted in the illegal disposal or release of hazardous substances or materials was responsible for the cleanup of the entire spill or release, not just the part of it that was his fault. Using this new legislative authority, KDNREPC contacted five responsible parties (RPs) identified as having sent drums to the A. L. Taylor site for "recycling": Ford Motor Co., Reliance Universal Inc., Louisville Varnish Co., George W. Whitesides Co., and Kurfee's Coating, Inc. These companies paid for the removal and disposal of the remaining drums on the site and subsequently reimbursed the USEPA and KDNREPC for much of the soil cleanup and site stabilization activities.

Once the immediate danger had been addressed, the EPA and KDNREPC began extensive negotiations with the RPs for a long-term remedy at the site. On the basis of technical, community, and cost factors, the remedy selected consisted of removal and off-site disposal of leachate or water present in the waste pits; stabilization of pond sediments, sludge, and other debris from low-lying areas; and installation of a cap across the waste now buried in the pits and elsewhere on the site.

The cap was the centerpiece of the remedial solution; it was made of a 30-inch- (76.2-cm-) thick layer of impermeable clay, overlain by an 18-inch- (45.7-cm-) thick layer of another impermeable material. A six-inch- (15.2 cm-) thick layer of topsoil was placed as final cover and planted with cover plants that had root systems that stabilized the topsoil and loam against erosion but will not penetrate the clay material of the cap. This cap is designed to prevent waste materials, or leachate, from being washed off the site by surface water.

A surface water drainage diversion ditch, which routes runoff around the capped area and can accommodate a 25-year 24-hour storm intensity, also was constructed. A monitoring program was implemented for Wilson Creek, to make sure contaminants were not leaving the site via a surface water flow pathway; groundwater monitoring down-

gradient of waste disposal areas also was part of site closure requirements. Finally, the site was secured with a six-foot- (1.8-m-) high chain-link fence and will be inspected regularly until 2016.

As directed by Congress, every five years, the EPA must evaluate the effectiveness of the remedies it has selected for each Superfund site. Four five-year reviews were conducted at the Valley of the Drums in 1992, 1997, and 2002, and 2007. In each case, the reviews concluded that the remedy implemented at the A. L. Taylor property remains protective of human health and the environment. The site was deleted from the National Priorities List in June 1996 and now serves only as a reminder of an era when the uncontrolled disposal of hazardous and toxic wastes constituted a major threat to the health and safety of the United States and its citizens.

See also AQUIFER; CHEMICAL CONTROL CORPORATION; LOVE CANAL; PAH; PCBs; PHTHALATE; SUPERFUND SITES.

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**Vermiculite Mountain Libby, Montana (2000–2007) Air Pollution** Vermiculite is a broad term applied to a set of minerals formed when groundwater has contact with and geochemically alters micas. Micas are aluminum silicate minerals that are common in igneous and metamorphic rocks. They have a distinctive cleavage, tending to split into

thin, flexible sheets, or plates. Vermiculite forms when water is incorporated into the laminar structure of magnesium-aluminum-iron silicate micas. Essentially, vermiculite is mica weathered by water introduced or added into the platelike structure of the mica sheets. Vermiculite forms most readily when two types of mica, biotite and phlogopite, are altered in this way.

An important industrial mineral, vermiculite has been used for almost a century as an insulator, sound deadener, soil conditioner, absorbent in packaging, and, most significantly, a fireproofing agent. Vermiculite is able to serve this wide range of uses because of its ability to exfoliate and expand (pop or puff) if heated at relatively low temperatures (1,472–2,012°F [800–1,100°C]) for only a few seconds. This expansion results when the water trapped between mineral layers is rapidly converted to steam. The expansion produces a 10-fold reduction in the bulk density of the mineral, from a dense 40–70 lb./ft.<sup>3</sup> (640–1,120 kg/m<sup>3</sup>) to a very light 4–10 lb./ft.<sup>3</sup> (64–160 kg/m<sup>3</sup>).

After it "pops," the processed vermiculite is lightweight, burns only at a high temperature, and readily traps air and water, making it suitable as an insulating agent and soil conditioner. It also changes size and shape, increasing to around eight to 12 times its original volume and forming small tubelike open-ended cylinders. This chemically inert, fire-resistant, and odorless material provides good thermal insulation and can absorb liquids such as fertilizers, herbicides, and insecticides, allowing them to be shipped as loose, free-flowing solids.

Today, most of the world's vermiculite is obtained from mines in South Africa, China, Brazil, and Zimbabwe. It also is mined in the United States, from deposits along the eastern Appalachian Mountains in Virginia and South Carolina. In the early 1920s, the United States was poised to become the world's largest producer of vermiculite, with the major source of this material a newly opened mine in the small town of Libby, Montana.

#### BACKGROUND

The Libby vermiculite deposit was discovered in 1919 when a local hotel owner decided to try his luck at gold prospecting. He visited some old workings at a nearby mountain, and, although he did not find any gold, he did notice that the rocks that had contact with his open-flame carbide lantern sputtered and popped when he stood too close to them. Curious, he sent a sample of the material to the U.S. Bureau of Mines, which subsequently informed him that the material was vermiculite and quite valuable. This man eventually sold his hotel, mortgaged his



ranch, and, by 1924, had become a full-time miner, building a small plant to size and exfoliate (pop) the vermiculite after it had been removed from the open pit he was digging. By 1925, the material was being shipped around the country, used to insulate bank vaults and added to roofing asphalt to improve its durability and fireproofing. In 1926, more than 100 tons (90.7 metric tons) of vermiculite per day was produced from the Libby workings.

The geology of the Libby vermiculite plays an important role in the environmental and public health effects related to its exploitation and widespread use. The Libby mine is about seven miles (11.3 km) northeast of the town, just above the banks of Rainy Creek. The bedrock in this part of northwestern Montana is made up of very old (about 600 million years) metamorphosed sedimentary rocks. Later (250 million years ago), an alkaline-ultramafic magma forced its way into this bedrock. This igneous intrusion is known as the Rainy Creek Complex, and, as the molten mass cooled, minerals such as biotite were formed. This and other minerals crystallized in the molten magma in a predictable pattern and formed concentric zones within the solidified rock mass.

The vermiculite at Libby was not formed until after the Rainy Creek Complex had been injected and

allowed to cool. As hot saline fluids from the solidifying rock mass and surrounding country rock as well as from later igneous intrusions encountered the biotite of the Rainy Creek Complex, the black micas began to change. Hydrothermal alteration is a chemical reaction in minerals brought about by hot fluids moving through the rocks. It was this hydrothermal alteration, combined with subsequent near-surface weathering processes, that carried the water into the crystallographic structure of the biotite and created vermiculite. The hydrothermal solutions also reacted with the mineral pyroxene, which is widespread throughout the Rainy Creek Complex, and intimately associated with the biotite, to form the mineral amphibole.

It was this geochemical reaction (the creation of amphibole) that would later result in the deaths of at least 200 people, the bankruptcy of a Fortune 100 company, and one of the nation's most extensive Superfund cleanups.

### CONTAMINATION OF THE AREA

An important group of more than 60 different rock-forming minerals, amphiboles are present in most igneous and metamorphic rocks, and almost all are harmless. They form at lower temperatures and



**Les Skramstad (right) developed asbestosis from working in the W. R. Grace vermiculite mine in Libby, Montana. He opposes mining industry efforts to limit lawsuits in asbestos cases. Seattle, 2003. (AP Images)**

always in the presence of water. Five major amphibole minerals—amosite, also known as grunerite or cummingtonite; crocidolite, tremolite, actinolite, and anthophyllite—can form asbestiform minerals. A sixth type of asbestiform mineral, chrysotile, is not an amphibole but belongs to a class of minerals called serpentines.

*Asbestiform* is a morphological term used to describe the appearance or habit of a mineral that has crystallized or grown in a single dimension. These types of crystals form long fibrous threads with length-to-width ratios of 20:1–100:1 or greater. When stressed, asbestiform minerals do not shatter; rather, the fibrous crystals bend and are pulled apart, sometimes breaking into shorter strands. Nonasbestiform varieties of tremolite, actinolite, and anthophyllite also occur naturally.

Asbestiform minerals have great economic significance. They are resistant to acids and strong bases, are effective electrical and thermal insulators, and the highly flexible and mechanically durable fibers can be easily woven or incorporated into cloth or other materials such as cement or asphalt. This group of minerals generally has been lumped together and defined as or called asbestos and has been used in brake linings, fireproofing compounds, and hundreds of types of building, flooring, and roofing materials. Despite all these useful properties, by the late 1970s asbestos began to be phased out of general use in the United States. The reason is that when inhaled, asbestos fibers can result in damage to the respiratory system and may even cause cancer. Recent studies have indicated that the amphibole forms of asbestos are more hazardous than the chrysotile type. This is because, when broken, the amphibole asbestos fibers are brittle and needle sharp. The chrysotile asbestos fibers are more flexible and arcuate and tend to do less damage when inhaled and lodged in the lungs.

The vermiculite at Libby is closely associated with asbestiform amphiboles, particularly tremolite, although winchite and richite, two other, less common varieties of amphibole asbestiform minerals, also are present in significant amounts. When the vermiculite ore at Libby was extracted and processed, asbestos-laden dust was released. Also, asbestos remained in the final product and was released during shipment and placement of the material.

Mining at the Vermiculite Mountain deposit was not a technologically challenging procedure. The ore body was within a few feet of the surface, covered only with a thin layer of soil. Once this was stripped off, the ore was dug out with standard excavating equipment, loaded onto large trucks, and driven to the mill for processing. Later, an open conveyor

was installed to transport the raw ore from the mine workings and deposit it in huge piles at the mill near town. The ore was then graded or sized and heated with steam until it popped. The finished product, named Zonolite, was then bagged or loaded into railcars for shipment. In some cases, unprocessed ore was sent to distant processing mills, some as far away as New Jersey, for exfoliation (popping).

In 1939, the original operations merged with another mining company, which began extracting ore in a different area of the deposit, and the Zonolite Corporation was formed. In 1963, W. R. Grace purchased Zonolite Corp and quickly expanded mine and processing activities, and soon the Libby workings became the world's largest producer of vermiculite, supplying more than 80 percent of this material. Mr. William R. Grace founded the company that bears his name in 1854 in Peru, where he bought and shipped bat guano for use as fertilizer. Over the years, Grace has changed from primarily a shipping and transportation organization into one of the world's largest specialty chemicals and materials companies with more than 6,000 employees and \$2.5 billion in annual sales.

Between 1963 and 1990, Grace and its on-site management team operated the mine efficiently and cost-effectively, realizing more than \$180 million in after-tax profits from the sales of Zonolite and Zonolite-based products. These operations were flawed in one very serious way: Every step of Zonolite mining, from extraction through exfoliation and shipping, produced dust. Asbestiform minerals were in that dust.

Through the 1970s and 1980s, as the dangers of both occupational and nonoccupational exposure to asbestos fibers became well known, the U.S. Environmental Protection Agency (EPA) began to take an interest in the workings at Libby, especially when, in 1978, workers at a chemical fertilizer plant in Marysville, Ohio, began to exhibit symptoms of asbestos-related diseases. This plant had used vermiculite ore in its fertilizers, and Libby vermiculite was thought to be the source of asbestos that had damaged the workers' health. On the basis of this information, the EPA began to focus on the potential risk of asbestos-contaminated vermiculite. In 1982, it sampled vermiculite at three major U.S. mines, including Libby. Other factors, however, intervened to shift EPA scrutiny away from Libby and vermiculite.

### INACTION OF REGULATORY AGENCIES

First, laboratory findings of the vermiculite samples reported that asbestos fibers in the samples were less than 1 percent, not considered significant at that

time. Next, EPA was beginning to feel national pressure to do something about asbestos in schools. The agency regarded asbestos-contaminated vermiculite as a less significant risk than asbestos-containing materials in schools and commercial or public buildings. As a result, EPA redirected its enforcement resources to these other asbestos materials and products. Grace quietly ceased operations at the Libby mine in 1990 because the price of vermiculite was falling as a result of recent discoveries in Africa and Asia, and the Montana operations were no longer profitable.

In 1992, a citizen wrote a letter to EPA complaining about potential exposure to asbestos when a building at the inactive vermiculite-processing mill was torn down. EPA referred the complaint to the Montana Department of Environmental Quality (DEQ), which investigated and found that the demolition had taken place without removing the asbestos from the building or taking the appropriate steps to prevent its airborne release, which are required under the Clean Air Act. The mine owner, Grace, was fined more than \$500,000.

Another citizen complaint, in 1994, identified blowing dust from the inactive mill site and an adjacent unused haul road as having an adverse impact on the health of Libby's residents. Once again, the Montana DEQ investigated, collecting soil samples from the mill site and haul road. Although asbestos was found in the samples, the DEQ did not take any action because the asbestos detected in the vermiculite at the mill site and on the road was not considered to be commercial asbestos. Commercial asbestos is asbestos that is produced from the mining of asbestos ore. Vermiculite was not mined for its asbestos content and, therefore, was exempt from regulation under the Clean Air Act. In 1995, the EPA advised the citizen that neither the DEQ nor EPA planned any action based on the DEQ's findings.

Nothing happened for more than five years at Libby, except that many of its citizens grew sicker. In 1999, a groundbreaking series of investigative reports published in the Seattle newspaper the *Post Intelligencer* titled "Uncivil Action—a Town Left to Die" pushed the problems of Libby into the forefront of national attention. The story told of the deaths and illnesses of more than 500 current or former Libby residents exposed to the asbestos-contaminated vermiculite ore and asserted that asbestos from the Libby mine and mill was still present in schools, homes, backyards, and buildings throughout the town, continuing to be a major threat to public health.

In the face of such damning publicity, both the EPA and DEQ were forced to act. Shortly after the newspaper articles were published, the EPA sent an investigation team to Libby, where, along with an official from the Montana Department of Health, they interviewed residents, examined health records, and collected more than 2,000 soil, dust, and building material samples for asbestos analysis. They discovered that more than 30 percent of the samples contained asbestiform tremolite. The EPA and DEQ studies also identified several residents who had contracted nonoccupational asbestos-related diseases. Later investigations confirmed that between 1979 and 1998, the death rate in Libby of asbestosis was 40–80 times higher than that in other areas with similar demographic makeup, and, in 2001, X-rays of more than 6,700 Libby residents and former mine workers found that 18 percent had asbestos-related lung damage.

### THE CLEANUP

These and other findings finally compelled the EPA to begin cleanup activities at Libby in 2000. Their efforts ranged from digging up and replacing asbestos-contaminated soil in schoolyards and playgrounds to using special high-efficiency vacuum cleaners to remove asbestos-laden dust from people's homes. Remedial efforts at Libby continued through the end of 2007 and cost more than \$180 million. This does not include an additional \$7 million to address contamination at more than 170 sites in other parts of the country that received the asbestos-contaminated ore from Libby. The work was performed under the Superfund program, which authorizes EPA to force responsible parties to do the work. If the responsible party, in this case, Grace Company, is unwilling or unable to comply with a cleanup order, EPA can move forward with site remediation and recover its costs from those who caused the contamination.

In June 2009, EPA for the first time in history used its authority under CERCLA to declare a public health emergency in Libby. While no one will be evacuated, this declaration does help provide priority funding for cleanup activities. As a result of previous and ongoing cleanup actions by EPA and its contractors, the former vermiculite processing plants and other highly contaminated public areas have been remediated. Cleanups also have been finished at 1,100 residential and commercial properties. EPA completed asbestos stabilization and removal actions at 100 larger properties by the end of the 2010 construction season. The EPA estimated that 1,200–



1,400 remaining residential and business properties needed some type of cleanup.

### LEGAL ACTIONS AGAINST GRACE CORPORATION

Grace's response to the Libby contamination was carefully crafted to protect their business interests and to help ensure the survival of the company. EPA was forced to sue Grace for the Libby cleanup because Grace refused to pay, stating that the EPA was doing much more than just emergency remediation; it was "rehabilitating" the property, and rehabilitations costs were not recoverable under Superfund. The federal courts disagreed and ordered Grace to reimburse EPA more than \$50 million for the first phase of its work. As the number of asbestos-related lawsuits against Grace began to rise, filed by both workers and people who became sick as a result of using Zonolite and related products in their homes and businesses, the company filed for bankruptcy protection in 2001. Before this, however, it had transferred millions of dollars in assets to foreign subsidiaries. A bankruptcy court judge later ordered Grace to return those assets to control of its U.S.-based operations.

In 2005, the EPA and U.S. Attorney's Office filed criminal indictments against Grace and seven of its executives, including two former mine managers, of knowingly releasing asbestos into the air, thereby endangering miners, their families, and townspeople, and of obstructing the investigation efforts of the EPA. Part of the indictment accuses executives and managers of the mining company of allegedly concealing health risks at the mine. For example, one company memorandum, written in 1976 by one of the indicted executives, states that almost two-thirds of employees who had more than 10 years of service tested positive for lung damage. If convicted, the managers and executives faced up to 15 years in prison. As a company, Grace could be fined up to twice the profits it made from the Libby mine, estimated at \$140 million, or be ordered to pay restitution to the victims. The trial began in late 2006, after a failed attempt to change the venue from Missoula to San Francisco. Grace consistently and vehemently denied any wrongdoing, and, in May 2009, Grace (the corporate entity) and three former executives were acquitted by a Montana jury of charges of knowingly exposing workers and townspeople to asbestos and subsequently conspiring to cover up those exposures. Grace funds an extensive medical monitoring and prescription drug plan for the residents of Libby and donates regularly to the local hospital.

The former Libby mine has been sold to three local townspeople, who have not yet decided how to develop it. Up to 100 years worth of mineable vermiculite ore is estimated to remain below the mountain.

See also AIR POLLUTION; ASBESTOS; INDOOR AIR POLLUTION; INORGANIC POLLUTANTS; SUPERFUND SITES.

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**vinyl chloride** In most cases, when a chemical is found to pose an environmental and/or health threat, its usage declines. Vinyl chloride, however, is one of the highest-volume chemicals used in the United States with ever-increasing demand, and yet it is one of the most deadly. This high volume leads to a widespread distribution, which is demonstrated by its presence in at least 616 of the 1,662 current or former U.S. Environmental Protection Agency (EPA)–designated Superfund sites (on the National Priorities List). The widespread nature and threat to health and the environment led vinyl chloride to be named the fourth worst pollutant in the United States on the 2007 CERCLA Priority List of Hazardous Substances. As a result, its use was strongly limited in 1974 through the passage of the Safe Drinking Water Act by the U.S. Congress because of its adverse health effects. The problem is that vinyl chloride, which is also known as chlorethene, chlorethylene, monochlorethene, monovinyl chloride (MVC), and Troidur, is used by the plastics industry to produce the extremely popular polyvinyl chloride (PVC), for which there is no other source. Until some other method to produce PVC is found or a substitute for PVC is found, it is likely that



vinyl chloride will continue to be produced in ever-increasing quantities.

### PROPERTIES, USES, AND PRODUCTION

Vinyl chloride is a synthesized organic compound that does not occur naturally but can be formed in the natural environment through the natural breakdown of other synthesized organic compounds. It is a chlorinated aliphatic hydrocarbon that at standard conditions is a sweet-smelling gas that is extremely flammable and even explosive. If mixed with air, it produces a deadly and irritating gas rich in carbon monoxide, hydrogen chloride, and phosgene. It only forms a liquid under high-pressure or low-temperature conditions.

Vinyl chloride was invented in 1835, but an efficient method of producing it was not discovered until 1912. As a result, the first commercial production of vinyl chloride did not begin until the 1920s. Prior to 1974, vinyl chloride also had uses as a refrigerant, extraction solvent, aerosol propellant, ingredient in pharmaceuticals and cosmetics, and even as an anesthetic in medical procedures. Now, more than 95 percent of vinyl chloride is used in the production of PVC and its copolymers, which have an enormous variety of applications such as furniture, electric wire insulation and cabling, building and construction supplies, pipes and plumbing supplies, automotive parts and accessories, medical supplies, packaging of all types, industrial and household equipment, sporting and outdoor equipment, military equipment and supplies, resins and film, and numerous other applications from credit cards to compact disks (CDs) and digital video disks (DVDs). As a result of these vast applications, vinyl chloride ranked as the 17th highest-volume chemical produced in the United States in 1994 and the 18th in 1995. Production increased from the late 1970s at 6–9 billion pounds (2.7–4.1 billion kg) per year to the mid-1990s at 15 billion pounds (6.8 billion kg) per year, a growth rate of about 7 percent per year. By 2003, there were 13 producers and 10 suppliers of vinyl chloride in the United States, and the production growth rate continues at about 3 percent per year. Imports of vinyl chloride peaked in 1989 at 302 million pounds (137 million kg) per year and had generally declined to 168 million pounds (76.2 million kg) per year in 2002, while exports fluctuated from 685 million pounds (311 million kg) per year to a high of 2.3 billion pounds (1.03 billion kg) per year in 2000.

### ENVIRONMENTAL RELEASES

Vinyl chloride enters the natural environment almost exclusively through waste and emissions from the plas-

tics industry, which uses it, and the chemical industry, which produces it. High environmental exposure to it only occurs near these industrial sites or in hazardous waste sites and landfills where leakage has occurred. Outdoor air in both rural and urban areas in the United States generally contains lower levels of vinyl chloride than the detection limit of the equipment. It is also not generally found in drinking water, again below the detection limit of the testing equipment for all but 0.74–0.9 percent of the population. Industrial releases of vinyl chloride to the environment slowly declined from an annual rate of 1.4 million pounds (635,000 kg) in 1988 to less than 1 million pounds (454,000 kg) by 1990. In 2001, 49 manufacturing and processing facilities released 732,200 pounds (332,100 kg) into the air, 102 pounds (46 kg) into surface water, and 96,000 pounds (43,500 kg) into injection wells; 1,000 pounds (454 kg) was treated off-site, for a total of 827,300 pounds (376,100 kg). By 2006, releases were down to 561,803 pounds (255,365 kg). The states with the highest releases between 1987 and 1993 were Louisiana, Delaware, Ohio, Pennsylvania, and South Carolina.

Vinyl chloride released to the atmosphere exists in the vapor phase and degrades rapidly through gas-phase photochemical reactions with an estimated removal half-life of 1.5 days. It rapidly evaporates from shallow surface water at an estimated removal half-life of 0.8 hour to the atmosphere, where it breaks down quickly. In soil, vinyl chloride also evaporates quickly with a removal half-life of 0.5 day or less at depths shallower than four inches (10 cm). Evaporation is slower at deeper depths, and it is resistant to biodegradation under aerobic conditions. Vinyl chloride is highly mobile, and that which is not evaporated may leach quickly into the groundwater system, where it can undergo biodegradation under anaerobic conditions.

### ADVERSE HEALTH EFFECTS FROM EXPOSURE

Exposure to vinyl chloride can produce adverse health effects in both humans and animals. It mainly occurs in the workplace, near industry that uses or produces it, as the result of improper handling or through cigarette smoke, in which it occurs in small quantities. Acute exposure to vinyl chloride mainly affects the central nervous system, resulting in dizziness, sleepiness, and unconsciousness within five minutes, but recovery is quick when the source is removed. At higher levels, damage to the liver, lungs, heart, and blood system may occur, and it could be fatal. Dermal exposure will numb the skin and produce redness and blisters. Chronic long-term exposure to lower levels of vinyl chloride produces major liver damage,

nerve damage, and damage to the immune system. A generally very rare condition also results from exposure, in which blood flow is reduced to the hands, skin disorders develop on the hands and forearms, and the bones in the fingertips degenerate. Exposure can damage sperm and testes and result in reduced sexual function and irregular menstrual cycles. In animal studies, miscarriages increased and fetuses had reduced weight and delayed skeletal development with exposure, as well as an increase in cancer.

Vinyl chloride is designated as a group A chemical, human carcinogen. It has been clearly shown to increase the human occurrence of angiosarcoma of the liver, a very rare condition, and has been implicated in cancer of the liver, brain, lungs, lymphatic system, and the organs and tissues that produce blood. Animal studies support these findings with increases in both angiosarcoma and common liver cancer, as well as cancer of lungs, mammary glands, kidneys, skin, stomach, and Zymbal glands. Studies of cell cultures from humans, rodents, and other mammals exposed to vinyl chloride show genetic damage including mutations, deoxyribonucleic acid (DNA) damage, several types of chromosomal damage, and sister chromatid exchange.

### REGULATIONS ON HUMAN EXPOSURE

In response to these adverse health effects, federal agencies regulate the human and environmental exposure of vinyl chloride. The EPA drinking water standard is two parts per billion (ppb) or 0.002 milligram per liter of water, and all spills of one pound (0.45 kg) or more must be reported to the National Response Center. Exposure from consumption of organisms cannot exceed 2.4 ppb. The Occupational Safety and Health Administration (OSHA) has set a permissible exposure limit (PEL) of one part per million (ppm) in workplace air for eight-hour workdays and 40-hour workweeks. They further set a ceiling concentration exposure of 5 ppm for any 15-minute period throughout the day. The National Occupational Exposure Survey of 1981–83 conducted by National Institute of Occupational Safety and Health (NIOSH) found that 81,314 workers were exposed to vinyl chloride.

*See also* ORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE.

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### volatile organic compound (VOC)

A VOC is a class of organic compounds that are primarily hydrocarbons and readily evaporate. There are literally thousands of VOCs existing as solids, liquids, or gases at room temperature. Methane (natural gas) is by far the most abundant and, as with many others, appears to pose no health risk to humans in normal air. Other VOCs such as benzene, formaldehyde, and chlorofluorocarbons do pose direct health or environmental risks. Benzene, for example, is an industrial solvent that is a known carcinogen, as are many other such VOCs. These evaporated or aerosol VOCs are primary pollutants. There has been much publicity of late about the abundance of VOCs in indoor air and the efforts to reduce it. There are many new restrictions on the amount of VOC in paints, sealants, and other household items. Many of the VOCs that are not direct health threats can undergo photochemical reactions in the atmosphere in strong sunlight with nitrogen oxides to form ozone and other compounds that are harmful to human health. These are secondary air pollutants. The U.S. Environmental Protection Agency (EPA) estimates that more than 19.8 million tons (18 million metric tons) of VOCs is released into the air over the United States each year, about 34 percent from transportation sources and 50 percent from industrial sources.

### TYPES AND USES OF VOCs

It is beyond the scope of this entry to list all of the VOCs. The more common EPA-regulated VOCs

include acrylamide, benzene, carbon tetrachloride, chlorobenzene, chloroform, DCA (1,2-dichloroethane), DCB (dichlorobenzene), 1,1- and 1,2-dichloroethylene, ethylbenzene, formaldehyde, MTBE (methyl tert-butyl ether), PCE (tetrachloroethylene), styrene, toluene, TCB (1,2,4-trichlorobenzene), and TCA and TCE (1,1,1- and 1,1,2-trichloroethane). They have a variety of household and industrial applications. They are used as fumigants (DBCP and EDB), gasoline oxygenates (MTBE), organic synthesis compounds (1,1-DCE and vinyl chloride), refrigerants (CFC-11 and CFC-12), and solvents (carbon tetrachloride, DCA, DCE, methylene chloride, PCE, TCA, and TCE). They are also integral parts of fuels (benzene, ethylbenzene, toluene, and xylene) and trihalomethanes (chloroform). Considering the wide variety of applications in this list, VOCs are virtually everywhere.

Although many people think of such chemicals as only affecting industrial workers, VOCs are also commonly found in the home and office. Household uses of VOCs include paints, paint strippers, wood preservatives, aerosol sprays, cleansers and disinfectants, glues and adhesives, permanent markers, correction fluids, copiers and printers, moth repellants, pesticides, air fresheners, stored fuels, automotive products, hobby supplies, dry-cleaned clothing, miscellaneous solvents, and many building supplies. Recent studies found that concentrations of VOCs in the home are two to five times higher than those found outdoors. It was further found that after the application of paint, sealant, or stripper, the concentrations reached levels of up to 1,000 times outdoor background levels and remained so for several hours.

### **ENVIRONMENTAL EXPOSURE OF VOCs**

With the heavy usage of VOCs in so many applications, it is no wonder that it occurs throughout the environment. Considering that they are volatile, release to the atmosphere is the overwhelming mode. They are primarily released from evaporation of fuel but also from industrial emissions, agriculture, and even home applications. Around urban areas, industrial plants, and military bases, and after pesticide application, there can be significant accumulations that range from temporary to more or less permanent. These concentrations can cause health concerns but pale in comparison to that from ozone. The tropospheric ozone that is ubiquitous around the world is almost exclusively produced by the reaction of VOCs with nitrogen oxides in the atmosphere. By far, this is the greatest threat from VOCs in the environment, and there are no signs that it will be resolved in the near future.

The National Water Quality Assessment Program of the U.S. Geological Survey conducted a study of VOCs in drinking water in the United States from 1985 to 2002. They sampled 3,500 wells in 98 major aquifers and analyzed them for 55 VOCs. The results were that 90 of the 98 aquifers tested positive for VOCs of some sort. Using a threshold cutoff of 0.2 part per billion (ppb), which is lower than the typical 0.5-ppb limit imposed by the Safe Drinking Water Act on the worst VOCs, 80 percent of the wells tested were within safe levels. Domestic wells were less likely to be contaminated (14 percent had VOCs) than public water supply wells (26 percent), but less than 2 percent exceeded the 0.5-ppb threshold. About 75 percent of the 55 VOCs were found in the 3,500 samples, but only about 15 were common. The most abundant was chloroform at 7 percent because it is a disinfection by-product of the chlorination of water. The second most common was PCE at 4 percent because it is used as a solvent by more than 80 percent of dry cleaners. Third most common was MTBE at 3 percent overall because it is an oxygenation component of gasoline. It was found in much higher concentrations in New England and the Mid-Atlantic states because there are more cars there, but because MTBE is no longer required in gasoline as of 2006, it should decrease in the future. The solvent TCE was the fourth most common at 3 percent not only because it is heavily used, but also because it is a breakdown product of PCE. Some fumigants such as DBCP were low overall but formed local concentrations where there was heavy use. In Oahu, Hawaii, for example, 30 percent of wells tested positive for fumigants. There were other smaller concentrations related to industrial use.

### **ADVERSE HEALTH EFFECTS FROM EXPOSURE**

Health effects from exposure to VOCs vary greatly depending upon the compound. Some produce very few effects at all but very high concentrations. The most common effects from short-term exposure include eye, nose, and throat irritation; and allergic skin irritation, headache, dizziness, loss of coordination, nausea, memory impairment, fatigue, and general intoxication. Most people recover relatively quickly when removed from the exposure. Sensitive people and those who have asthma can have much more severe reactions even at low concentrations that may require medical treatment. At higher levels, VOCs can cause damage to the kidneys, liver, and central nervous system. Long-term chronic exposure to VOCs at much lower levels can also produce these health effects, including significant brain damage. Some VOCs are carcinogenic,

producing a variety of cancers at various exposure levels.

See also AQUIFER; BENZENE; CARBON TETRACHLORIDE; CHLOROFORM; DCB; DBCP; EDB; ETHYLBENZENE; FORMALDEHYDE; MTBE; NO<sub>x</sub>; OZONE; PESTICIDES; PCE; STYRENE; TCA; TCB; TCE; TOLUENE; XYLENE.

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**volcanoes** In addition to the utter devastation that volcanoes can cause purely through the force of eruption, they can cause levels of pollution of the atmosphere and surface of the Earth unequaled in a single event except that of an impact. Although the most impressive emission of a volcano is the glowing lava, it is insignificant compared with the volume of gases and particulate emitted in most subaerial eruptions. These emissions may be natural, but they are pollution, nonetheless, and may be even more damaging to the environment than anthropogenic pollution. They are capable of causing more radical climate change in a shorter period than all of the global warming caused by humans. Indeed, the success of humans over the past 10,000 years is owed in part to the lack of any large volcanic eruptions.

### AEROSOLS

There are two types of aerosols emitted during a volcanic eruption: particulate and liquid compounds. They can be released into the troposphere, where they directly affect humans, or they can be shot into the stratosphere, where they indirectly affect humans. In either case, the effects can be devastating depending upon the size of the volcano.

When a volcano erupts explosively, the emissions may be shot more than 10 miles (16 km) vertically from a summit eruption. The reason that they have such energy is that volcanoes along island arcs, such as the Aleutians, Caribbean, and Indonesia, or magmatic arcs, such as the Andes and Cascades, have a significant component of water incorporated into the magma. Some intraplate volcanoes such as the one at Yellowstone can also contain a lot of water. As long as the magma is under pressure, the water remains as liquid incorporated in it. This situation is analogous to the carbon dioxide in soda or beer, which remains in the liquid in closed containers. As long as the cap is on, no matter how much the bottle is agitated, it will not foam up. Release the pressure by removing the cap, and the carbon dioxide is released from the liquid as a gas. At standard conditions, a substance in the gas state will take up 22.4 times the volume the same amount will take up in the liquid state. For volcanoes, when the magma rises up the volcanic pipe, the pressure is released and the water and other volatile components convert to gas in an instant. At 1,768°F (1,000°C) or more, this instantaneous volume increase is hundreds to thousands of times, creating an explosion unequaled by the largest bombs.

### Stratospheric Aerosols

Large summit eruptions may shoot thousands of tons of aerosols into the stratosphere. The most common aerosols are ash, water, sulfur compounds, hydrochloric acid, and chlorine, depending upon the composition of the magma. Sulfur dioxide is typically the most plentiful and effective of the stratospheric aerosols. These aerosols can reflect back sunlight, preventing it from reaching the surface, thereby causing global cooling. The most famous recent eruption to produce such temporary climate change was the eruption of Tambora on Indonesia. In April 1815, this cataclysmic eruption emitted a column that reached a height of about 28 miles (44 km). It produced more than 36.6 cubic miles (150 km<sup>3</sup>) of solid particulate and delivered 200 million tons (182 million metric tons) of sulfur dioxide to the stratosphere. The volcanic cloud from Tambora spread over the entire atmosphere, and the sulfur dioxide reacted to form droplets of sulfuric acid. The reflected sunlight caused global temperatures to lower by as much as 5°F (3°C). Stratospheric aerosols are difficult to remove because there is no precipitation. Even a year after the eruption, most of the Northern Hemisphere experienced sharply cooler temperatures during the summer months. In parts of Europe and in North America, 1816 was known as "the year without a summer." Snow was reported



on the ground through June in New England and a worldwide famine ensued.

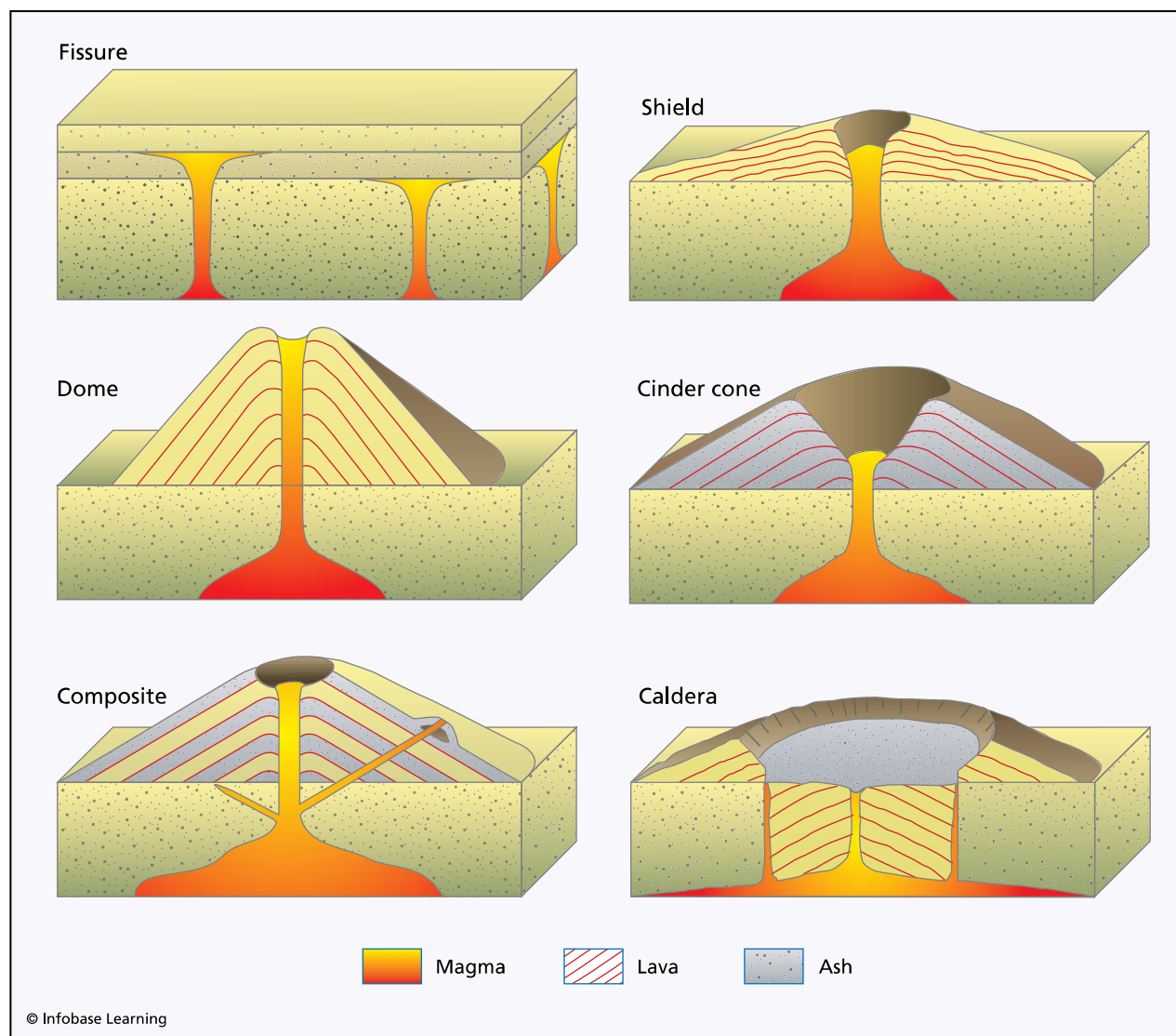
More recently, Mount Pinatubo erupted in the Philippines in 1991. It was a large eruption with a high column. Scientists estimate that Mount Pinatubo injected about 22 million tons (20 million metric tons) of sulfur dioxide into the stratosphere. The reflecting of sunlight cooled average global temperatures over the following year by about 1°F (0.5°C). There are many other examples of such cooling. These examples of minor cooling, however, pale in comparison to the potential eruptions. In comparison to the 36.6 cubic miles (150 km<sup>3</sup>) emitted by Tambora, Toba emitted more than 684 cubic miles (2,800 km<sup>3</sup>) 74,000 years ago, and Yellowstone emitted more than 610 cubic miles (2,500

km<sup>3</sup>) 600,000 years ago. The potential global cooling caused by an eruption of this nature could be catastrophic.

Aerosols also can produce chemical reactions in the stratosphere (heterogeneous chemistry). The most dangerous of the reactions are those that contribute to the destruction of stratospheric ozone and, thus, the ozone layer. The compounds most devastating to stratospheric ozone are those containing chlorine. Hydrochloric acid and free chlorine are not uncommon in certain eruptions.

### Tropospheric Aerosols

Many of the same materials that are incorporated in the stratospheric aerosols also appear in the troposphere. The difference is primarily in abundance



Block diagrams showing six most common types of volcanoes

but also the quantity and size of particulate. Gravity keeps the heavier particles closer to the surface, and they are the first to settle out. Pyroclastic material is volcanic particulate and classified by size and somewhat by shape. The larger fragments are called bombs and blocks (cobble and boulder size), lapilli (pebble size), and ash (dust size). The smaller sizes are the most common. Ash can spread out in the troposphere and be transported great distances before settling to the surface or being washed out by precipitation. Close to the volcano, it may accumulate enough to collapse weak structures. In most cases, it is just dangerous to breathe. Ash is primarily composed of volcanic glass fragments, especially pumice. It can cause silicosis and other scarring of the upper and lower respiratory system. If aircraft fly through plumes of ash, it is so abrasive that the engines can be destroyed, potentially causing a crash. It can also frost windows on aircraft and clog air intake vents. There have been several near-miss disasters of aircraft flying through ash clouds.

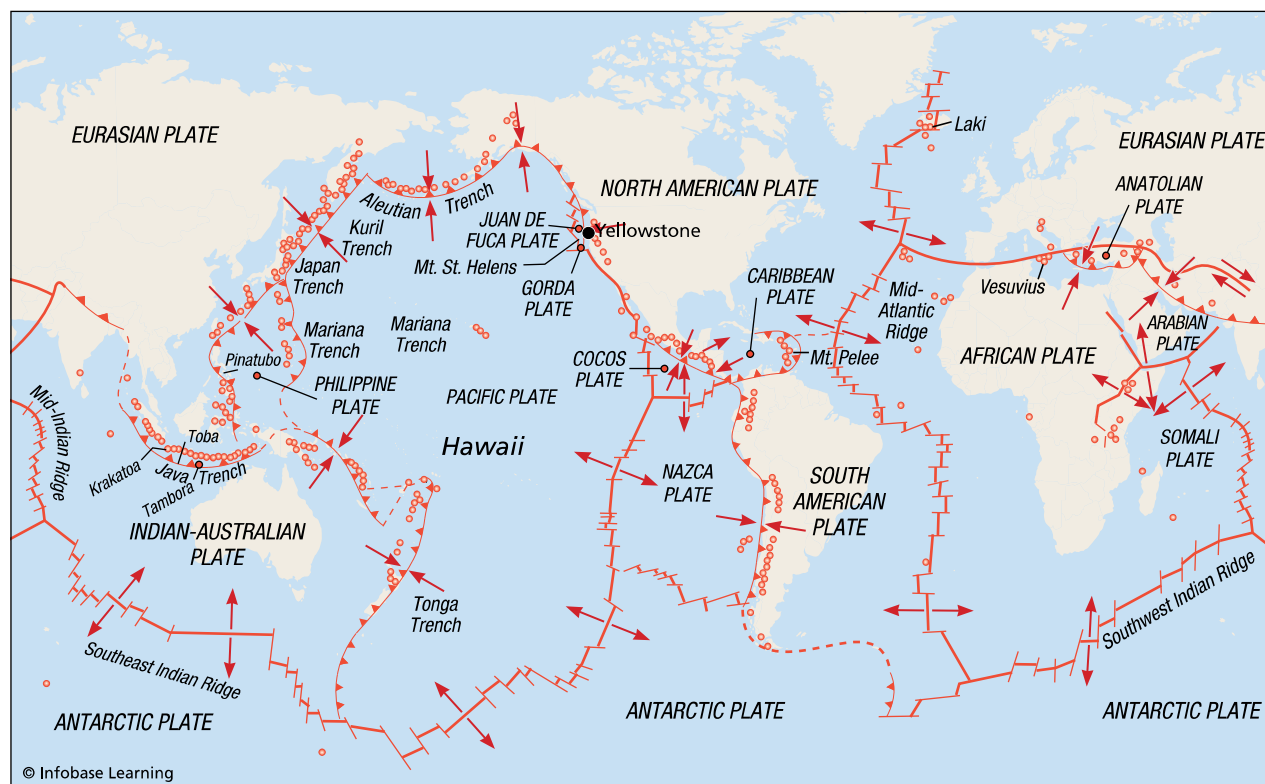
There is a huge number of chemicals emitted during the eruption of a volcano. A partial list of these chemicals includes sulfur dioxide, carbon dioxide, and carbon monoxide; numerous inorganic pollutants including lead, arsenic, chromium, cadmium, and mercury; and even organic compounds such as methane, benzene, and methylethyl ketone (MEK). Most of these compounds are in such small quantities that their contribution to the global pollution problem is negligible. Some chemical compounds, however, can be in quantities that can cause significant environmental problems to disasters.

The most common and abundant chemical pollutant from a volcano is sulfur. Through a series of reactions in the atmosphere, this sulfur is converted to sulfuric acid, which contributes to acid precipitation. The term *brimstone* refers to the sulfur that is emitted from a volcano, and many volcanoes are named for sulfur (Soufrière in the Caribbean, for example). For a single eruption, a large quantity of sulfur may be emitted but quickly dissipate in weeks to months after the event. In areas with prolonged volcanic emissions, however, significant acid rain may occur. In Hawaii, even though anthropogenic emission of sulfur is relatively low, there is a significant acid rain problem caused by the near-continuous volcanic emissions that must be monitored for health reasons. The Phlegraen Fields in central Italy also have had historical prolonged sulfur emissions. It is this area that served as the image of hell in Dante's *Inferno*. Other areas of extensive volcanic activity, as in Iceland, the Aleutians, and the Kurils, also have natural acid rain problems.



The June 1991 eruption of Mount Pinatubo, Philippines  
(AP Images)

In rare instances, other dangerous chemicals may be emitted in high enough quantity to present a problem. Light and volatile elements such as chlorine and boron are the most common. One of the best examples of this phenomenon was the Laki, Iceland, eruption of 1783. This eruption emitted basalt, which is usually relatively safe. This eruption, however, was the largest of its kind in historical times. It produced 3.5 cubic miles (14.7 km<sup>3</sup>) of lava, covering an area of 218 square miles (565 km<sup>2</sup>). Lava poured from the fissures at an astounding rate of 295,000 cubic feet (8,600 m<sup>3</sup>) per second. Accompanying the lava was a huge emission of fluorine gas that was deposited on all of the vegetation in Iceland. The fluorine poisoned all of the livestock that ate it, resulting in the deaths of hundreds of thousands of animals. The famine that ensued resulted in the deaths of 9,000 residents of Iceland, or 25 percent of the population at the time. A significant amount of the emissions remained in suspension over Iceland and all of



**Tectonic map of the Earth showing the major types of plates and many of the locations of known active and dormant volcanoes (circles)**

northern Europe for months after the eruption and caused a peculiar haze that was compared to fog.

See also AIR POLLUTION; BENZENE; CARBON DIOXIDE; MEK; OZONE; PARTICULATE; SULFUR DIOXIDE.

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# W

## **Waikele Naval Magazine Lualualei Valley, Hawaii (1993–present) *Soil and Water Pollution***

The Waikele Naval Magazine artillery arsenal was a 500-acre (202-ha) section of the Lualualei Valley on the leeward side on the island of Oahu, Hawaii, that hosted weapons, war, and hazardous waste. Located northwest of Pearl Harbor, the broad, flat-lying plains of this fertile bottomland made it ideal for farming, ranching, and military operations. In 1930, the U.S. Navy began acquiring property in the Lualualei Valley from private owners and the territorial government. By the end of 1931, almost 8,000 acres (3,238 ha) had been purchased and earmarked for a new weapons storage depot, which opened in 1934.

During World War II, the Lualualei Valley served as the primary ammunition and materials storage depot for the Pacific theater for all three branches of the service. Today, the 7,500-acre (3,035-ha) Naval Magazine Pearl Harbor, or NAVMAG, contains 250 aboveground storage units that can hold almost 80,000 tons (72,575 metric tons) of ordnance. The 300 military and civilian employees who work on the base are responsible for the care and maintenance of the largest reserve of conventional and nuclear weapons east of the Korean Peninsula. As in any well-designed military installation, the weapon and ammunition storage areas are dispersed for reasons of security and safety. Within the Lualualei Valley, the West Loch and Waikele subareas, or extensions, support the facility's overall mission. West Lock serves as the valley's main ocean shipping and receiving dock, as well as hosting the navy's Undersea Warfare Center.

## **THE POLLUTION AND CLEANUP**

The 500-acre (202-ha) Waikele extension, or “branch,” storage area is largely undeveloped, with a topography that consists of a level upland, separated from a lower, more eroded lowland by a steep cliff or bluff. A steep, well-maintained road connected the upland, which housed the entrance, administrative areas, barracks, and other support facilities, to the lowland, where weapons storage, transfer, and operations took place and where 20 tunnel magazines are carved into the cliffs of the bluff to protect them from air attack and to reduce the chance of a catastrophic explosion. Waikele is an inactive site, decommissioned in 1993 and declared surplus property. After more than 50 years of operation, however, environmental studies identified a number of areas where chemicals and munitions residue might have been released or disposed of on the property. To address potential public health and ecological impacts from these areas, the navy is currently in the process of remediating soil contamination at Waikele as part of its ongoing nationwide environmental program, managed by the Environmental Restoration Division of the Naval Facilities Engineering Command. This cleanup, performed in cooperation with both the U.S. Environmental Protection Agency (EPA) and the Hawaii State Department of Health, will allow the eventual reuse of the property. Five areas at Waikele are in the process of being remediated.

## **Firing Range**

Most outdoor firing ranges contain a row of paper, wood, or metal targets in front of a sand or earthen impact berm. The bullet passes through the target



and becomes lodged in or is captured by the impact berm. Lead is the preferred metal for bullets and other types of projectiles because it is heavy, inexpensive, and easy to mold or shape. Once the lead bullet, which is sometimes coated or jacketed with a layer of copper, penetrates the impact berm, it can pose a serious environmental risk. Lead can enter the ecosystem either as dust from physical abrasion through fragmenting or ricocheting or as mechanical and chemical weathering mechanisms begin to dissolve it and make the lead more bioavailable.

The small-caliber firearms firing range at Waikele is in the upland part of the site and its floor and impact berm contain extensive amounts of lead. Lead has also been detected in sediment samples from drainage areas downstream of the range. To address this contamination, lead-containing soil and sediment will be excavated and disposed of at an appropriately licensed off-island waste management facility. After postexcavation samples confirm

the removal of impacted materials, the area will be backfilled with clean soil.

### **Burn Pit Area**

This one-acre (0.4-ha) area of the Waikele lowland was the location where ordnance shipping containers were burned and other debris such as metal, glass, and concrete was discarded. Arsenic and lead have been detected in isolated areas (hot spots) in subsurface soil. These hot spots will be excavated and the impacted soil consolidated in a central location underneath a vegetative cover. Land use controls will be implemented for this area, which includes both a fence to prevent unauthorized access to the area, as well as a deed restriction that prevents its use for residential purposes and ensures that the vegetative cover will not be disturbed. The navy also will implement a long-term maintenance and monitoring program to maintain the integrity of the vegetative cover.



**A photograph of 1940 munitions storage bunkers at Naval Magazine Lualualei, Waikele branch, Waikakalua and Kipapa Gulches, Pearl City vicinity, Hawaii (Library of Congress)**

### Building 21

In this former vehicle maintenance and paint shop, use and surface disposal of spent chlorinated solvents and leaded paint sludge occurred. When they were poured down floor drains and used in weed control, they contaminated soil and groundwater in this area of the Waikale facility. The primary contaminant, carbon tetrachloride, is present in groundwater at almost 60 parts per million (ppm), well above the action level of 5 ppm. Ongoing monitoring indicates that the carbon tetrachloride is not migrating. The navy's proposed remedial plan for this area is to excavate and dispose of contaminated soil and to implement an enhanced natural attenuation remedy for groundwater. The enhancement is the injection of substrate to stimulate bacterial degradation of carbon tetrachloride and chloroform, its breakdown product.

### Underground Storage Tanks

Diesel fuel and gasoline were stored in 1950 vintage steel underground tanks in the upland area of Waikale. These tanks, which were removed in 1993, released petroleum hydrocarbons, including ethylbenzene, toluene, and naphthalene, into soil and groundwater at concentrations in excess of Hawaii Department of Health action levels. In response to the results of a pilot study, the navy plans to install a soil vapor extraction and bioventing system within the contaminated area. This remedial approach will expedite bacterial breakdown of petroleum hydrocarbons remaining in the subsurface at the site.

### Building 66

Building 66 was used as a battery storage and maintenance facility. Spent electrolytic fluids were poured onto a sloped area and contaminated underlying soil with lead. In addition, waste batteries were buried over a several-acre area near the building. The navy is carrying out an extensive excavation project to remove both the batteries and lead-affected soil. These materials will be disposed of at an EPA-approved facility on the U.S. mainland.

The remedial activities being conducted by the navy must balance several competing interests. They need to be protective of public health and the environment with a balance of costs against the risks posed by conditions at the site. They must also take into account the financial limitations of the navy's environmental restoration program budget. Finally, remediation planning must take into account the needs and desires of local residents, business people, and adjacent landowners. The navy's proposed actions will make the majority of Waikale avail-

able for reuse. This process, called in navy jargon a FOST: Finding of Suitability to Transfer, means that the property can be restored to civilian use, but that the navy retains responsibility to address contamination remaining at the site.

*See also* ARSENIC; CARBON TETRACHLORIDE; ETHYLBENZENE; IN SITU GROUNDWATER REMEDIATION; LEAD; NAPHTHALENE; TOLUENE; UNDERGROUND STORAGE TANK.

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**war and pollution** Considering that war is meant to kill people, concern for the environment or public health during conflict is a very low priority. In terms of human casualties, it should be. For example, the D-day battle of World War II produced an immense amount of pollution. Bullets dumped tons of lead into Normandy beaches; bombs and other incendiary devices emitted phosphorus and sulfur compounds into the air and water; diesel fuel from ships and landing equipment spilled into the ocean; and fires and explosions released polycyclic aromatic hydrocarbons (PAHs) and many other chemicals into the air. Considering, however, that 5,500 young American men lost their lives, the number killed or having suffered to any degree from pollution is inconsequential. Even marine life suffered far more from the bombs exploding on the beach and in the shallow waters than it did from all of the pollutants. As Dwight D. Eisenhower, 34th president of the United States and commander of

the allied forces that went ashore on D-day, said in a speech on April 16, 1953:

Every gun that is made, every warship launched, every rocket fired signifies in the final sense, a theft from those who hunger and are not fed, those who are cold and are not clothed. This world in arms is not spending money alone. It is spending the sweat of its laborers, the genius of its scientists, the hopes of its children. This is not a way of life at all in any true sense. Under the clouds of war, it is humanity hanging on a cross of iron.

Some of the worst environmental disasters, however, are related to military action or its preparation, from the burning of the oil fields during the 1991 Persian Gulf War to the environmental problems at nearly every military base and military supplier in the United States.

### EARLY CONFLICTS

Even early conflicts were not environmentally friendly. Vegetation was trampled during battles, exposing bare soil. Removal of cover vegetation

increased erosion during subsequent rains and silted the local streams and ponds, producing a form of water pollution. In dry weather, open soil produced windblown particulate as air pollution. Invariably, settlements were burned, producing more air pollution, consisting of polycyclic aromatic hydrocarbons (PAHs), additional particulate, methyl ethyl ketone (MEK), and other pollutants depending upon what was burned. Later, fire was used directly as a weapon by employing wood, straw, and other vegetation and later using burning oil and other flammable substances. These advances further increased particulate emissions as well as the pollutants related to burning. Burning oil also added directly to soil pollution and later to water pollution in runoff after subsequent rainstorms. The partially burned hydrocarbons produced a number of pollutants, from PAHs to creosote and other organic pollutants, such as benzene or xylene, depending upon the type of oil. The environmental threat of these compounds in such high concentrations was not trivial.

Preparation for war was also costly to the environment. Once humans reached the Bronze and Iron Ages, smelting of ore to produce metals for weapons and body armor produced significant pollution in



Oil well fires set by retreating Iraqi forces burn outside Kuwait City in aftermath of Operation Desert Storm, 1991



the areas associated with mining and processing. Waste rock from mining operations polluted soil in the area, and subjecting fresh rock and ore surfaces to weathering greatly increased the amount of heavy metals in the soil and runoff. These heavy metals included lead, chromium, mercury, zinc, cadmium, arsenic, and others, depending upon the ore. Smelting operations greatly increased air, soil, and water pollution with heavy metals as well as sulfur, phosphorus, and other elements and compounds released from the ore. Fires used in processing also added particulate and organic pollutants to the air in quantities that could be significant. Considering the short average life span for humans during this time, it is doubtful that anyone even noticed that the metalworkers and others in those areas had shortened lives if they were, in fact, shorter.

Perhaps the first documented use of pollution as a weapon of war was in Carthage, North Africa. When Hannibal crossed the Italian Alps to face the Romans in battle in the first century B.C.E., he did not plan well and lost a significant part of his army including elephants to snow avalanches and exposure. This is because he attempted to cross in October rather than in summer. As a result, even though he gave the Romans a good fight and a better scare, he was defeated. He was forced to run a hasty retreat back to Carthage with the Romans close on his heels. When the Romans defeated Hannibal and took Carthage, in order to ensure that Carthage would never rise again, they plowed salt into the soil to make it unfit for agriculture. The salt was used as a chemical weapon. Similar use of salt took place in Spain and Portugal on the lands of convicted traitors through the middle of the 1700s.

### DEVELOPMENT OF CHEMICAL WEAPONS

Besides the salt and burning oil, humans continued to develop chemical weapons to increase their effectiveness in war. The Dark Ages in Europe saw only small advances, if any, but in China, the development of gunpowder changed the face of war forever. Once its effectiveness as a weapon was realized, gunpowder was widely produced and used. Mining and processing operations to obtain, refine, and produce sulfur, saltpeter, and charcoal and to mix them into gunpowder greatly increased pollution at those sites. The burning of gunpowder also produces smoke (particulate) that contains sulfur and organic compounds that pollute the air. After battles, this smoke hangs heavily over the battlefield and can be caustic. Given that large numbers of people lost their lives from the physical effects of gunpowder, namely, being struck with projectiles, concern for

this pollution was nonexistent. There was even less concern when lead was used for bullets even though the quantity added to major battlefields could be significant and last for centuries.

Just as with the earlier chemical weapons, hundreds of years passed before any real advances occurred. In the 19th century, the great advances in chemistry eventually made their way to the battlefield. The first chemicals introduced were medicinal, including drugs and anesthesia. It was not long, however, before chemicals were also used as weapons.

### World War I: The Chemical War

Chemical weapons were first widely used in World War I, and they produced horrifying results. It is estimated that some 88,500 people died directly from exposure to chemical weapons and another 1,240,850 were injured. The weapons were referred to as poison gas, though some were simply vapors from liquids. Even though they were greatly feared and caused the most hideous of deaths, they were not particularly effective, causing only about 4–5 percent of the total casualties and being easily rendered ineffective by weather conditions and later by protective clothing. The first chemicals used were various types of tear gas that were launched in shells. The idea was to incapacitate the enemy temporarily to make them easier targets for the infantry. Tear gas was used at the beginning of the war in the form of ethyl bromoacetate, first by the French on August 19, 1914, and then by the Germans on October 19, 1914. Neither of these early deployments was particularly effective; nor was the use of xylyl bromide (t-stoff) by the Germans on January 19, 1915. It was also relatively easy to avoid the effects simply by wearing goggles.

The first time chemicals were used to kill enemy troops directly was on April 22, 1915, when the Germans deployed chlorine gas against the French at Ypres, France. The chlorine was released from canisters and formed a green cloud that wafted over the enemy position. Chlorine is a powerful irritant that attacks the eyes, nose, throat, and lungs. It forms hydrochloric acid and other acids when combined with water that strip off the membranes in the affected areas. At high doses, it can cause pulmonary edema and death by asphyxiation. Early uses were especially effective because soldiers would try to outrun the cloud and thereby spend more time inhaling the chlorine as the cloud overtook them and they would inhale it more deeply into their lungs from panting. The canister deployment also proved to be a problem when at Loos, France, a chlorine gas cloud was blown back over British troops after they had released it. For that reason, gas began to





Trinity atomic bomb test site in New Mexico, July 16, 1945 (Los Alamos National Laboratory Archives) trinity-200

be loaded into shells for release directly in the enemy ranks. Chlorine gas was not used alone for long because it was found that simple masks were relatively effective at filtering it.

Later in 1915, the Germans began to use phosgene, a much deadlier chemical. Phosgene is a liquid below 47°F (8°C) but when heated becomes a gas that is four times as dense as air. To help it spread better, it was typically mixed with chlorine and loaded into canisters with a white star, thus its battlefield name. It is estimated that some 80 percent of the deaths from chemical warfare resulted from exposure to phosgene. The high density would allow it to hug

the ground and fill the trenches that characterized the battle tactics of World War I. Phosgene can only be smelled at high enough doses to cause irreparable damage, and even then it is easily mistaken for newly mown grass. At this point, it causes burning of the eyes and nose, blurred vision, difficulty in breathing, nausea and vomiting, lesions, pulmonary edema, and death of heart failure. The problem is that it is even deadly at lower than detectible concentrations. Soldiers could unknowingly be exposed to it and not show symptoms for up to two days. Then the same pulmonary collapse would occur and ultimately be fatal.

The most notorious of the chemical weapons of World War I was mustard gas, or sulfur mustard. Otherwise known as bis(2-chloroethyl) sulfide, mustard gas was first used by the Germans in September 1917. Mustard gas is a blistering agent that especially attacks any moist area. At high doses, it can strip away flesh to the bone. At battlefield doses, symptoms may not have appeared for two to 24 hours. At that point, headache and fever developed, and then the skin and mucus membranes blistered and were stripped away. Pneumonia set in, but death did not occur for four to five weeks. In the meantime, the victims were so wracked with pain that they had to be strapped to their beds. Anything touching their skin, even clothing or bandages, put them in agony. They were typically put on a bed beneath a tent made of sheets. Whereas most injured soldiers were stoic and quiet in the hospitals, mustard gas victims cried and groaned from the extreme discomfort. Luckily, by the end of the war, soldiers were so accustomed to gas attacks that they were equipped with relatively sophisticated gas masks and protective clothing, and gas attacks were less common. Deaths from mustard gas were far fewer than from phosgene or chlorine. On the other hand, mustard gas was determined to be a known human carcinogen, causing increased risk of lung and other respiratory cancers, by the International Association for Research on Cancer (IARC). More than 28,000 American soldiers were exposed to nonlethal doses of mustard gas in World War I and 15,000–60,000 soldiers were exposed for experimental purposes after the war.

The horror of chemical weapons was recognized by all participants of World War I. For this reason, they were banned in the Geneva Convention/Protocol of 1925. Chemical weapons saw minimal use in World War II and only by mistake, or so it was claimed. Nonetheless, the United States was producing 40,000 pounds (18,000 kg) of chemical weapons by the end of World War I and continued to produce and stockpile them until 1968. By then, it had accumulated more than 34 million pounds (15,400 metric tons). In 1997, the United States signed the Chemical Weapons Convention treaty, which required the destruction of all chemical weapons by 2007. In a statement made on April 7, 2008, the United Nations secretary general, Ban Ki-moon of South Korea, announced that more than 29,800 tons (27,000 metric tons) of chemical weapons in almost 3 million storage or delivery containers had been verifiably destroyed. Remaining stockpiles were expected to be eliminated by 2012. The 183 countries participating in the program represent 98 percent of the world's population.

Mustard gas was used in the 1936 Ethiopian War and in the 1984–88 Iran-Iraq War. Otherwise, its introduction into the environment from chemical weapons occurred only through leaks and spills from manufacturing, transportation, and storage. Phosgene, on the other hand, is used in the production of some plastics. In 2005, it was found that the amount of phosgene in the atmosphere was much higher than previously anticipated. Considering that phosgene contributes to the destruction of the ozone layer, this was not welcome news. Chlorine is widely used as a disinfectant and a bleaching agent. It is released to the environment on a daily basis from numerous industrial and residential sources. It is also highly toxic. These sources are unrelated to war, which only amplifies their negative effects on the environment.

### World War II Chemicals

Although chemical weapons were generally not used in World War II, there were other pollutants that were widely released. There was far more use of petroleum products for both transportation and weaponry. There was extensive warfare using ships, airplanes, tanks, trucks, and jeeps, all of which required gasoline or diesel fuel. With transportation mishaps, destruction of these vehicles during war, and vehicle exhaust, huge amounts of dangerous pollutants were released to the environment. Fuel was also used in weaponry in flame throwers in many campaigns and directly pumped into the cave systems of the volcanic islands of the western Pacific (Guadalcanal, Iwo Jima, etc.), where it was ignited. The gasoline used in flame throwers was mixed with a jellylike substance that was first derived from rubber but later a compound of naphthalene and palmitic acid called napalm. Bombs were more sophisticated and plentiful during World War II. Incendiary types of bombs included large amounts of phosphorus and napalm, among other dangerous substances. Napalm produces so much carbon monoxide that most people pass out near the explosion and are subsequently burned. It was heavily used in the Korean War as well. Pesticides including dichlorodiphenyltrichloroethane (DDT) were used to clear areas of disease carrying mosquitoes in swamps in several campaigns. The infrastructure of most countries had also advanced quite a bit after World War I. When chemical factories were destroyed during bombing missions, far greater quantities of much more dangerous chemicals were released to the environment. On the whole, there was far more pollution released during World War II than World War I.

Not directly used for battles but a well-used product nonetheless was Zyklon B, or cyanide, which



**Incendiary bombs being dropped from U.S. Army Air Corps B-29 Superfortress on Kobe harbor, Japan, June 1945** (AP Images)

fueled the gas chambers in the Nazi concentration camps. The Nazis crowded as many people as possible into small, tightly sealed rooms and then released a

tablet of Zyklon B, which vaporized immediately and caused a quick death by asphyxiation. Millions of noncombat civilians were executed in this manner and



burned in crematoriums. This atrocity, which includes the Holocaust as its major component, is certainly one of the darkest chapters in modern civilization.

Another chemical weapon that was developed during World War II was nerve gas. The problem with the gas weapons used in World War I was that soldiers could fight for a day or two before symptoms appeared. This lapse could be enough to win a battle or replace the injured soldiers. There was a need for a weapon that incapacitated troops immediately, and nerve gas was the solution. Although little was actually released during the war, much was manufactured. The first nerve agent was developed by accident in a laboratory that developed pesticides in Germany on December 23, 1936. This agent is called tabun (also known as GA) and was extremely potent on insects, but an accidental spill proved that it was also potentially lethal for humans. As was required by law, a sample was sent to the Nazi high command in May 1937. Once it was evaluated by the

German military, the entire research team was relocated to a top-secret research lab for the duration of World War II. The research team developed other nerve agents as well, including sarin in 1938, soman in 1944, and cyclosarin in 1949, otherwise known as GB, GD, and GF, respectively. The G refers to the country of origin (Germany) and the second letter refers to the order of the experimental compound.

Nerve agents are organophosphorus cholinesterase inhibitors that attack the nervous system of the victim. Normally, muscles contract and relax. Nerve agents inhibit acetylcholinesterase in tissues, resulting in excess acetylcholine, which does not allow the muscle to relax. Symptoms of exposure to vapor appear within seconds to a few minutes, whereas exposure to liquid may take up to 18 hours depending upon dose. Initial symptoms include runny nose, tearing, constricted eye pupils, and eye pain. They are quickly followed by blurred vision, coughing, excess salivation, tightness of the chest,



**Zyklon B (blue stains), a gaseous cyanide-based insecticide that was introduced into chambers such as this one in Majdanek, Poland, killed thousands of people during World War II. (USHMM, Archiwum Panstwowego Muzeum na Majdanku)**



and rapid breathing. As the cascade of events continues, the victim urinates, defecates typically with diarrhea, and becomes confused, drowsy, and weak with muscle spasms, headache, nausea, vomiting, abdominal pain, and irregular heart rate and blood pressure. Finally, the victim loses consciousness and has convulsions and paralysis before dying of respiratory failure. The entire sequence takes about two minutes to loss of consciousness and less than two more minutes to death.

The Nazis began plans for plants to produce nerve agents on a large scale as soon as they learned about their potency. A pilot plant was set up in 1939 and construction of a major plant was begun in 1940. As a result of the difficult nature of production, the plant did not become operational until 1942, and it remained in operation for 2.5 years before its capture by the Soviet army. There were more than 300 accidents including 10 fatalities even before the plant was opened. It is estimated that the plant produced between 10,000 and 30,000 pounds (4,545 and 13,636 kg) of tabun during the period. When sarin was invented in 1939, plans to build

plants for its production began immediately. Several smaller plants were operational and produced between 1,100 pounds (500 kg) and 10 tons (9.1 metric tons) depending upon the estimate. Sarin, tabun, and soman were loaded into artillery shells and readied for use against Allied targets but never used. There is evidence that the Nazis believed the Allies also had nerve agents and would retaliate if the Nazis used them.

The second group of nerve agents, called the V-series, were similarly developed by mistake, this time in Great Britain. Similarly to the G-series events, research on organophosphate compounds for use as pesticides was being carried out at a commercial laboratory. The first of these compounds was marketed as Amiton in 1954, but it was far too toxic for commercial use, and it was removed. The military took control of research on Amiton and renamed it VG, the V ostensibly for “venomous,” though the accuracy of the claim is unconfirmed. Other members of the V-series include VE, VM, and the most infamous, VX. The V-series of nerve agents have several advantages over the G-series in that they are about 10 times as power-



**Bombed-out Nuremberg, Germany, 1945.** The twin-spired Lorenz Church is in the distance, and a statue of Kaiser Wilhelm I is at right. (USHMM; National Archives and Records Administration, College Park)

ful and far more persistent. The United States entered the chemical weapon arena in 1958 when they traded information on the development of thermonuclear weapons with the British for their VX technology. By 1961, the United States had begun its own research and production program on chemical weapons.

The only real documented use of chemical weapons in war was the Iran-Iraq War of 1981–88, in which VX and tabun were used. Sarin was used in a terrorist attack in the subway system of Tokyo, Japan, in 1995. There are other reports of nerve gas leaks from storage facilities but none was major. The real threat of toxic gas may result from its mishandling. Until 1972, the military disposed of unwanted chemical weapons by dumping them into the ocean. They disposed of 32,000 tons (29,090 metric tons) of mustard gas and nerve gas in 26 poorly located dumpsites off 11 states on the east and west coasts. The U.S. Congress banned the practice at this point. The problem is that if the dumped steel drums leak, the nerve agent could persist for up to six weeks in the ocean, during which time it would kill every susceptible marine organism. It is suspected that part of the marked decline in marine life in the coastal United States may be the result of this leakage. The problem is that scientists have no idea whether the drums have leaked or by how much.

### Vietnam War

The Vietnam War relied primarily on conventional weapons. Therefore, most of the environmental effects were similar to those in previous wars. The main differences were in two areas, Napalm-B and Agent Orange. Although Napalm-B, or “supernapalm,” was invented much earlier than the war, it saw greatly increased usage. The *B* was added to the name because it no longer contained naphthalene or palmitic acid, but benzene and polystyrene instead. The burning of Napalm-B produces an abundance of partially burned hydrocarbons and carbon monoxide in addition to the usual by-products of petroleum burning. Agent Orange is a defoliant that was widely sprayed from helicopters and airplanes to increase visibility and speed of passage in the jungle. It was used from 1961 to 1971 before being banned. Its name derives from the color of a band on the drums in which it was stored. Agent Orange was at the center of a lawsuit by Vietnam veterans because it contains dioxin, which has been shown to cause various forms of cancer, among other problems.

### RADIATION AS A WEAPON

Radiation is probably the most deadly threat to the environment of all weapons and yet was one of

the quickest to progress from scientific discovery to weapon. Radiation was discovered in 1895 by the Curies, husband and wife, in France, and by the late 1930s, it was already being tested for use as a weapon. Radiation was only used directly as a weapon twice, both times by the United States and both times against Japan in an effort to end World War II with as little loss of life and scarce resources as possible. Radiation was used in the form of the atomic bomb (A-bomb), which was developed in the United States by a team of top scientists known as the Manhattan Project.

The Manhattan Project was the most concerted scientific effort to develop a weapon of all time. It involved the cooperation of British and American scientists in several top-secret laboratories around the United States. The effort had its roots in several prewar events. In 1934, Enrico Fermi, an Italian physicist and winner of the Nobel Prize in physics, conducted an experiment in which he was able to split a uranium atom, producing nuclear fission. This experiment was repeated in 1938 by German scientists just as Germany was claiming Czechoslovakia. When Germany invaded Poland in 1939, thus beginning World War II, great concern arose that Germany was developing a nuclear fission weapon in their laboratories. Separate projects in Britain and the United States were begun in 1939 in response, but neither was particularly effective. It was not until 1942, when General Leslie Groves, an army engineer who had just finished overseeing the construction of the Pentagon, assumed military responsibility for the project, that any significant advances were made. The project was named for the U.S. Army Corps of Engineers district in New York City and combined British and American efforts but excluded the Soviet Union. Scientific leadership was given to the American physicist Robert Oppenheimer, who immediately enlisted the help of the many prominent scientists fleeing Europe as well as those in the United States. He set up extensive laboratories throughout the United States and Canada to conduct this top-secret research. Some developed into small cities that remain today, including Los Alamos, New Mexico; Oak Ridge, Tennessee; and Hanford, Washington, all of which have significant pollution issues.

The first breakthrough in the Manhattan Project occurred on December 2, 1942, when Enrico Fermi produced the first self-sustaining nuclear chain reaction in a small laboratory under the stadium at the University of Chicago. The coded message from one of Fermi's colleagues, the physicist Arthur Compton, to James Conant, the chairman of the National Defense Research Committee, declared (in a very understated manner) the triumph of the experi-

ment by saying, “The Italian navigator has landed in the New World,” and this success began a race to produce a controlled reaction suitable for use in a weapon. Two methods to produce a reaction would emerge, one involving a gun-type assembly and the other involving an implosion assembly. The gun assembly involved shooting one subcritical mass of uranium 235 (U-235) into another mass to produce a supercritical mass that would undergo a fission reaction. The problem in the development of this bomb was separating U-235 from U-238 and determining the amounts needed to drive the reaction in a weapon. The implosion assembly involved the focused energy from high-explosive lenses on a plutonium core to initiate the chain reaction. Plutonium 239 does not exist in nature and must be produced by processing uranium 238 in a nuclear reactor. The challenges in this bomb were the separation of U-238, the converting of uranium to plutonium, and the determination of proper quantities to achieve critical mass. Both development efforts ran simultaneously and somewhat competitively.

The first nuclear test was carried out in the New Mexico desert on July 16, 1945, under the code-name Trinity. The bomb was a plutonium implosion device nicknamed “the gadget” that delivered an explosion with a blast equivalent to 19 kilotons (17,300 metric tons) of trinitrotoluene (TNT). Even the mightiest of bombs was dwarfed by this explosion. As a result of the success of this test, President Truman ordered the bombing of Japanese cities to preclude a lengthy invasion campaign, which would result in the loss of millions of lives. As a result, on August 6, 1945, the city of Hiroshima was destroyed by a uranium gun-assembly bomb code-named Little Boy, but Japan refused to surrender. On August 9, 1945, the city of Nagasaki was destroyed with a plutonium implosion assembly bomb code-named Fat Man. The blasts killed more than 100,000 people apiece outright, and nuclear fallout would kill tens of thousands of people from radiation sickness over the next several years. It is this unanticipated radiation that posed and perhaps still poses an environmental threat many years after nuclear testing has ceased.

Although the Manhattan Project was treated as top-secret, it did not escape spyings. President Truman was surprised when Prime Minister Stalin showed no concern at the announcement of the atomic bomb. The reason was that the information delivered by his spies allowed the Soviet Union to jump-start their own nuclear program. On August 29, 1949, the Soviet Union tested their own atomic bomb, code-named Joe-1 by the Americans. In those early days of the cold war, this development shocked and scared Americans enough that they rushed to

achieve dominance once again. The fear allowed a fringe of the Manhattan Project to achieve prominence. As early as 1942, it was recognized that nuclear fission could generate enough energy to initiate nuclear fusion, the process that powers the Sun. Enrico Fermi suggested that this process might lead to a “superbomb” but did not pursue it, as most of the Manhattan Project group did not favor devoting the time and energy. Edward Teller, a Hungarian-born physicist and close colleague of Fermi, however, continued to research the process against the wishes of his superiors. Even after the Soviet test, Robert Oppenheimer, the head of the Atomic Energy Commission, which succeeded the Manhattan Project, still did not favor development of a fusion bomb. He was overruled when on January 31, 1950, President Truman announced that the United States would develop a fusion, or hydrogen, bomb.

The program, led by Teller, was high priority and as such yielded quick results. The first hydrogen bomb was constructed in a project code-named Operation Ivy. The device, code-named Mike, was detonated on November 1, 1952, on Elugelab Island in the Marshall Islands. The device was more than 20 feet (6 m) high, weighed 140,000 pounds (63,636 kg), and yielded a blast equivalent to 10.4 megatons (9.5 million metric tons) of TNT, 450 times as powerful as the Nagasaki bomb. It obliterated the island and left a crater 6,240 feet (1.9 km) wide and 164 feet (50 m) deep. Although the products of fusion are less dangerous than fission products, in order to initiate the fusion reaction, a primary fission reaction is necessary. A fissionable jacket around the fusion fuel aids in the compression and heating. When the fusion reaction initiates, it obliterates the radioactive fission material into the explosion cloud. The environmental danger of this process was recognized on February 28, 1954, when the United States detonated its first thermonuclear weapon. The bomb, known as Shrimp, was detonated at Bikini Atoll, Marshall Islands, in a test that was code-named Castle Bravo. It delivered a blast equivalent to 15 megatons (13.6 million metric tons) of TNT that produced a radioactive cloud that covered 7,000 square miles (1,446 km<sup>2</sup>). A snowlike mist of nuclear fallout covered several islands, which had to be evacuated and are still uninhabitable, as well as a Japanese fishing boat—the *Lucky Dragon*. Crew members died; the contaminated fish actually went to market.

If there had been only a few tests, the potential environmental impact of nuclear testing might have been minimized. By the time of the Castle Bravo test, however, the Soviet Union had already conducted a thermonuclear test. On August 12, 1953, the device, code-named Joe-4 by the United States, was detonated. It was a relatively small blast, but by 1955



the Soviet Union had developed and tested a device that could yield megaton explosions. This is how the arms race began. The late 1950s and early 1960s saw numerous tests of ever-larger devices with nuclear fallout distributed worldwide by weather systems. This fallout settled on vegetation, into the soil, and into the water and was consumed by humans and animals throughout the time and beyond. The largest device was the Soviet Tsar Bomb, which was tested in October 1961 at 50 megatons (45.5 million metric tons) of TNT, which was a reduced load. In its full state, it would have yielded a 100-megaton (91-million-metric-ton) blast, which on its own could have significantly increased radioactive fallout.

All nuclear tests were either underwater or aboveground in the early days. In 1958, the United States, Soviet Union, and United Kingdom agreed to a test moratorium, but it was short-lived when the Soviet Union began testing again. In 1963, the Limited Test Ban Treaty, which eliminated the testing of nuclear weapons in the atmosphere, underwater, or in outer space, was signed by 116 countries. It did not limit underground tests, which were still conducted frequently. China, which was not one of the 116 participants, violated this treaty in 1992. In 1967, the United States, Soviet Union, and United Kingdom signed the Outer Space Treaty, which banned testing on extraterrestrial bodies. The 1968 Nuclear Non-Proliferation Treaty was signed by 133 countries and made permanent in 1995. The limiting and destruction of nuclear weapons began in the 1970s with the Strategic Arms Limitation Treaties (SALT), which were initiated because there was far more killing power stockpiled in nuclear weapons than there were people on the planet. There were three SALT treaties, two in 1972, which limited the number of antiballistic missiles (ABM) and intercontinental ballistic missiles (ICBM), and one in 1979, which limited payloads. Treaties that began in the late 1980s resulted in the destruction of a large part of the nuclear arsenal of the United States and Russia. The 1987 Intermediate-Range Nuclear Forces Treaty (INF) banned short- and intermediate-range missiles. The 1991 and 1993 Strategic Arms Reduction Treaties resulted in the destruction of a significant part of the nuclear arsenal in the United States and Russia. The 1996 Comprehensive Test Ban Treaty (CTBT) banned underground testing and established a monitoring network to enforce the ban, but the treaty was not signed by India, which continued testing. Currently, there are at least nine countries that have nuclear capability—the United States, United Kingdom, Russia, France, China, India, Israel, Pakistan, and North Korea—and possibly South Africa and Iran. Most have done significant testing.

See also BENZENE; CYANIDE; DIOXIN; PAH; PHOSPHORUS; RADIATION; RADIOACTIVE WASTE.

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### Waste Isolation Pilot Plant *Chihuahuan Desert, New Mexico (1999–ca. 2070)*

The world's first engineered repository for the permanent disposal of transuranic (TRU) radioactive and transuranic mixed wastes is located 26 miles (42 km) southeast of Carlsbad, New Mexico, in a remote part of the Chihuahuan Desert. Most TRU wastes are composed of protective clothing, tools, glassware, equipment, soils, and sludge contaminated by radioactive materials at nuclear weapon production facilities. Only defense-generated transuranic wastes can be shipped to Waste Isolation Pilot Plant, or WIPP. The 60-building WIPP complex in rural New Mexico represents the combined efforts of thousands of scientists and engineers working over a 50-year period at a cost of billions of dollars to develop a system to manage, store, and dispose of the nation's most toxic, defense-related radioactive waste safely. The facility is not permitted to accept high-level radioactive wastes or spent nuclear fuel generated from commercial power reactors. It is likely that those types of wastes will be shipped to Yucca Mountain, Nevada. Radioactive wastes are classified, described, and disposed of by using precise criteria.

### BACKGROUND

A 1957 National Academy of Sciences Report first recommended the disposal of radioactive wastes in salt beds or salt domes. These types of geologic repositories are particularly well suited for waste disposal for a number of reasons. They have good thermal conductivity and high radiation resistance. The salt readily dissipates the heat produced by the decaying radioactive isotopes, and its crystallographic structure tends to remain intact when exposed to high levels of radiation. Salt beds are relatively impermeable and are self-healing. Water does not readily enter or move through a salt formation because it becomes saturated and crystallizes new salt crystals. When a fracture forms or an open area is excavated, the salt recrystallizes to fill and heal the fracture or mined area and thereby can seal the radioactive waste from the environment. For the same reason, salt domes are commonly excellent oil reservoirs. The water and hydrocarbons are trapped and cannot escape to the surface or migrate around the salt beds.

In 1980, after an extensive environmental and site characterization program, the U.S. Congress authorized the Department of Energy (DOE) to establish a geologic repository in a salt formation in New Mexico's Permian Basin. This repository was designed to accept for permanent disposal of almost 6 million cubic feet (175,000 m<sup>3</sup>) of "contact handled TRU

waste" including materials with levels of radioactivity low enough so that they can be handled directly by workers using standard safety precautions and equipment. It can also handle approximately 25,000 cubic feet (2,323 m<sup>3</sup>) of "remote handle TRU waste," which includes materials with levels of radioactivity that require special, noncontact, or remote handling procedures.

Construction at WIPP began in earnest in 1983 and continues today. This site was chosen because it contains no circulating groundwater, is in a geologically stable area in terms of earthquakes and volcanic eruptions, and can be excavated deep enough to allow for a safety buffer of the same rock both above and below the designated disposal depth. It also helped that the Department of the Interior's Bureau of Land Management owned the land and the site had low population density.

The state of New Mexico bitterly fought the establishment and development of WIPP, but in 1996 Congress passed and President George H. W. Bush signed the WIPP Land Withdrawal Act Amendments, transferring ownership of the property to the DOE and withdrawing it from public use. Disposal of TRU wastes at WIPP takes place 2,150 feet (655 m) below ground in the 2,000-foot- (610-m-) thick Salado Formation, a salt layer deposited about 225 million years ago. The sparse desert rainfall (less than 10 inches [25.4 cm] per year) minimizes the amount of water that may infiltrate the waste.

### WASTE DISPOSAL

Four vertical shafts have been completed to the 2,150-foot (655-m) disposal depth, where there are seven disposal chambers or rooms, each measur-



Loading boxes of radioactive waste for disposal at the Waste Isolation Pilot Plant southeast of Carlsbad, New Mexico, 1999 (DOE Photo)

### RADIOACTIVE WASTE TYPE AND DISPOSAL

Waste Form	Description	Disposal
High-level waste	Spent fuel, concentrated liquid, or solid residuals produced by reprocessing spent fuel from commercial nuclear power plants. Nuclear fuel reprocessing is no longer done in the United States. Primary isotopes contained in high-level waste generally include cobalt 60, strontium 90, cesium 137, and iodine 129. A large nuclear reactor generates approximately 30 tons (27.2 metric tons) per year of spent nuclear fuel.	None available (Yucca Mountain, Nevada, being developed as a possible site)
Low-level waste	Low-level waste includes clothing, containers, animal carcasses, medical isotopes, depleted uranium, and other materials that have contact with radiation or are slightly radioactive. Accounts for 90 percent of all radioactive waste produced in the United States.	Commercial disposal facilities
Mill and mine tailings	Low-level radioactive waste that includes rock, sand, and other residues remaining after uranium, radium, or thorium has been mined. These high-volume, low-activity wastes contain about 80 percent of the radioactivity present in unprocessed ore.	Managed under DOE's Uranium Mine Tailing Remedial Action (UMTRA) Program
Mixed wastes	Low-level waste containing both hazardous and radioactive constituents. For example, scintillation fluid, in which a beta-emitting nuclide is dissolved in an aromatic solvent such as toluene, is a mixed waste.	Commercial disposal facilities
NORM—naturally occurring radioactive material	A number of earth materials contain radioactive materials that, if concentrated for commercial purposes, may pose a special health risk. Coal contains U and Th, as well as radium 210 and lead 210. Mineral sands are composed of titanium minerals, zircon (U-rich), and monazite, a rare earth mineral containing thorium. Tantalum concentrates used in the automotive and electronic industries are derived from pegmatite minerals, which contain U and Th. Phosphate rocks are used for fertilizer and contain U and Th. Oil and gas production residues contain radium 210 and lead 210.	Managed according to individual state regulations
TRU—transuranic wastes	Radioactive waste that contains more than 3,700 Bq/g of elements heavier than uranium (atomic number greater than 92). Artificially produced by the irradiation of nuclear fuel and most often associated with weapons production. Very radiotoxic because they decay by emitting high-energy alpha particles. Examples include plutonium and americium.	WIPP

ing 300 feet (91.4 m) long, 33 feet (10 m) wide, and 13 feet (4 m) high. The final facility design includes 56 rooms to hold about 850,000, 55-gallon (208.2-L) impact- and flame-resistant, high-integrity containers filled with TRU waste. Above-ground, WIPP's primary operations are centered at the 84,000-square-foot (7,804-m<sup>2</sup>) Waste-Handling Building, where containers of TRU wastes are unloaded, inspected, inventoried, and prepared for transport underground. Other support buildings include a health physics laboratory, exhaust filter building, emergency generators, and staff offices.

WIPP also operates its own fire department, ambulance, and mine rescue service. WIPP became operational in March 1999, and disposal operations will be ongoing through 2070. By 2006, WIPP had already received and permanently disposed of 5,000 shipments of TRU waste.

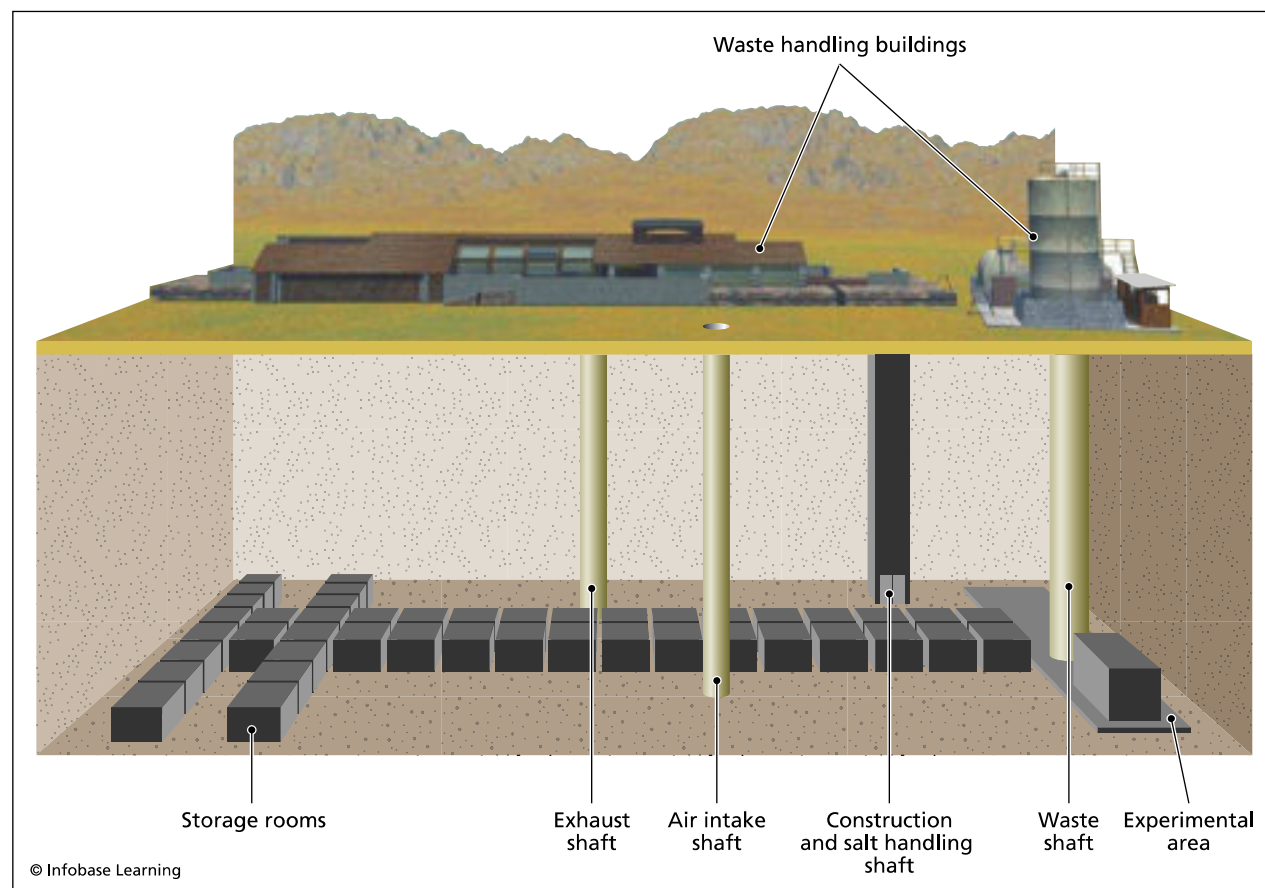
WIPP operations and TRU disposal are not without controversy or environmental risk. Because of their very long half-lives, transuranic wastes remain radioactive for thousands of years. WIPP has been designed to keep the waste isolated from the environment and people for more than 10,000 years. Facility

performance is based on a series of complex and sophisticated computer models developed specifically for the project that attempt to anticipate environmental conditions not decades or even hundreds of years into the future, but millennia. Whether these models are accurate, only our distant ancestors will know, although DOE has built in a number of design safety factors to try to account for future unknowns.

Perhaps the largest risk associated with disposal at WIPP is that related to inadvertent human intrusion. This part of New Mexico does have oil and gas and potash mining that is done in the vicinity of the plant. One potential failure scenario is the breach of disposal system integrity by someone drilling for oil or gas centuries from now, when land use controls at the repository site may have been forgotten or lost through deteriorating government records.

Water has been observed within the hollowed-out rooms, or panels, where TRU wastes are being placed for disposal. The presence of this water a half-mile (0.8 km) below the surface in the salt disposal layer raises questions about the long-term integrity of the waste containers because salt water corrodes most metals. Similarly, the possible inter-

action of waste and water, producing pressurized gases, could force radioactive material to the surface or into overlying water-bearing zones. The Salado Formation, however, is a relatively impermeable, stable geologic unit, which is isolated from groundwater by other impermeable rocks above and below it. The DOE thinks that the water in the disposal horizon was deposited with the salt or that it is water that has leaked down access and ventilation shafts or along old, improperly sealed boreholes that were drilled for oil and potash exploration purposes before WIPP was established. Site opponents disagree and interpret the water to show that the site is hydrologically connected to overlying and underlying water-bearing zones. So far, the DOE's extensive scientific analysis has been able to convince federal and state regulators as well as a large majority of the scientific community that water intrusion issues at WIPP are manageable and well within design performance parameters for the facility. There are nearly 30 sites around the United States that store TRU wastes in places ranging from outdoor pools to locked warehouses. Assembling those wastes in one central location that has been specially constructed



Cutaway subsurface block diagram showing the various components of the Waste Isolation Pilot Plant (WIPP) in New Mexico

and is heavily monitored is a sensible way to reduce overall public health and environmental risks posed by these very dangerous materials.

*See also* AQUIFER; COBALT; RADIOACTIVE WASTE; RADIUM; YUCCA MOUNTAIN WASTE REPOSITORY.

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**water pollution** According to the U.S. Environmental Protection Agency (EPA), water pollution is the greatest threat and has caused the greatest amount of ecological damage of any form of pollution. It has not caused as many human casualties as air pollution events, but it has caused unparalleled damage to marine and aquatic life, birds, and ecosystems. The really devastating incidents of water pollution involve accidental and intentional spills of chemicals or fuels into surface water systems. Pollution of groundwater systems involves the leaching and downward movement of surface spills and leaks, leaching of surface applications of chemicals such as pesticides, infiltration of leachate from a landfill, and leaking of underground storage tanks (USTs), among others. Such pollution is typically not as immediately devastating as a spill but can have long-term effects on large numbers of people that may only be recognized in retrospect.

Water pollution can be divided into two general types, surface water pollution and groundwater pollution, depending on whether the release is purely on the surface or infiltrates the soil and enters the subsurface. Both surface water and groundwater pollution can be caused by identifiable point source

releases or large-scale nonpoint source slow releases. Although surface water releases can be ecologically catastrophic, groundwater releases tend to be much slower but can involve large amounts of pollutant. Surface water pollution can further be in marine environments or terrestrial environments.

### SURFACE WATER POLLUTION

There are many forms of surface water pollution and many cause serious problems. Unlike groundwater, surface water undergoes no mechanical filtering—input must rely completely on degradation by microorganisms, aeration, and exposure to sunlight. Some pollutants break down readily under these conditions, whereas others persist unhindered. Depending upon the volume of the spill or the frequency of small spills, the natural system may be quickly overwhelmed and ecological damage can result. In many instances, these two types of surface water spills have been devastating.

Surface water can be polluted in a number of ways. The large-volume spills are typically composed of undiluted chemical, which is mainly some type of fuel or petroleum derivative. These are primarily less dense than water—light nonaqueous-phase liquids (LNAPLs)—and thus float on the surface, largely affecting the top and edges of the body. Chemicals that are denser than water—dense nonaqueous-phase liquids (DNAPLs)—sink to the bottom and affect bottom sediments and bottom-dwelling organisms. Cleanup of such spills is usually a long and complex process with a high potential for errors and collateral damage.

Surface water is also polluted on an everyday basis both by accidental and deliberate low-volume spills and long-term processes. The release of pollutants can be from identifiable point sources and large-area nonpoint sources. By volume, most pollution is from surface runoff. Spilled oil and gasoline, pesticides and herbicides, fertilizers, road salt, and creosote from tar are just a few of the numerous chemicals that are swept into ponds and lakes or storm drains and transported into streams and rivers. The pollutants can be transported in aqueous form as mixed liquid, or they may be carried in suspension as particulate or attached to particulate.

Most heavy metal inorganic pollutants are of limited solubility and are physically eroded from soil and transported as particulate in suspension to and within surface water. Some organic compounds may attach to organic or clay particles in soil and may also be carried in suspension into surface water bodies. Both of these types of pollutants settle into the bottom sediments. While the inorganic pollutants



## CEMETERIES AND GROUNDWATER CONTAMINATION

The Paleolithic is that period of human history and development that began roughly around 2.5 million years ago and ended at around 10,000 B.C.E. with the advent of agriculture and fixed settlements or villages. During this time, humans evolved into their current body shapes. They learned how to use tools and survived by organizing into family-based clans of 50 or 60 people and following animal herds and foraging for edible plants. Toward the end of the Paleolithic, about 200,000 years ago, *Homo sapiens* began to emerge as the dominant humanoid life-form. Migrating from the African savannahs and quickly spreading across Asia, Europe, and the Americas, *Homo sapiens*'s larger brain, fully upright carriage, and capacity for complex thought and language gave this species a remarkable evolutionary advantage over their human cousins. Within 500,000 years of their appearance, no other humanoid life-forms were present on the planet.

### DEATH AND DISPOSAL OF DEAD BODIES

As *Homo sapiens* began to appear, so did the custom of burying the dead. Burial grounds and mounds dating back 200,000 years contain the remains of early *Homo sapiens* along with tools, clothing, and other indications that our ancestors disposed of their dead in a ritualistic manner. Burial in prehistoric times, as today, is done for a combination of reasons, both practical and spiritual. Upon death, with the cessation of its natural defense mechanisms, the body is almost immediately assaulted by a wide variety of decomposing bacteria for food and energy. Bacteria-induced decay of dead bodies results not only in the formation of foul-smelling gases but also in the spread of diseases. In actuality, according to a United Nations World Health Organization report, survivors of natural disasters are unlikely to become ill from contact with decaying bodies, and quick burial of the deceased may divert critical resources that should be spent in assisting the living in recovery efforts. Pathogenic organisms inside the human body such as *Escherichia coli* do not survive long once typical human metabolic functions cease, and the spread of disease after natural disasters is actually related to poor-quality drinking water, lack of adequate sanitation, overcrowding in refugee camps, inadequate medical care, and the lack of other critical infrastructure that may be missing or destroyed after a disaster. Health care workers, military personnel, and rescuers who have contact with dead bodies are at greater risk of contracting such infec-

tious diseases as hepatitis B, hepatitis C, human immunodeficiency virus (HIV), enteric pathogens, and *Mycobacterium tuberculosis*. Training and use of appropriate protective equipment, however, can minimize exposure risks.

Burial also prevents scavengers from devouring the body. On a more psychological or spiritual level, burial helps the family and loved ones of the dead accept the death and can reduce the sadness associated with it. In addition, many religions require burial as a condition of the deceased's having access to a pleasant and fulfilling afterlife.

### ENVIRONMENTAL EFFECTS OF HUMAN BURIAL

Human burial, however, has environmental consequences. In many Western countries, the concentration of dead bodies in belowground cemeteries, in combination with the chemicals used to preserve them, could result in serious groundwater contamination. Embalming is intended to protect or slow the process of decay. It is done to allow a period of mourning to occur without disruption by the physical biological degradation processes that would otherwise naturally occur. One of the earliest methods of corpse preservation was mummification, practiced by the ancient Egyptians as well by Inca and certain Peruvian cultures, most of whom believed that a well-preserved body would empower the dead in the afterlife. During the Crusades, crude embalming was done to allow the bodies of fallen noblemen to be shipped home for burial in a hygienic manner. As medical technologies developed, embalming chemicals became more sophisticated as embalmers borrowed and improved upon procedures and techniques used by biological researchers to preserve their laboratory specimens. The following summarizes some common burial customs.

#### 1. Christian

Embalming is permitted and the body usually is interred in a casket and placed in an above- or below-ground concrete vault or soil grave, depending upon local custom. In many traditions, the remains are buried face up, in an east-west direction, to view the coming of Christ on Judgment Day.

#### 2. Judaism

Embalming is not permitted and the coffin is constructed with no metal parts (wooden pegs instead of nails) to permit quick decomposition of the remains.

### 3. Islam

Embalming is not done and burial takes place in a cloth shroud without a casket so as not to delay decomposition. The face is pointed toward Mecca at the time of burial.

### 4. Hindu

Cremation is the preferred method, although some groups practice burial. Infants are more often buried than cremated. At the funeral site, in the presence of the male mourners, the closest relative of the deceased (usually the eldest son) ignites the funeral pyre. After cremation, ashes and fragments of bone are collected and eventually immersed in a holy river.

In the United States, embalming began to be widely used after Abraham Lincoln's death. His well-preserved embalmed body impressed the thousands who saw it as the corpse made its way via train across the country from Washington, D.C., for burial in Illinois. Finally, the basis for modern-day embalming technology was established in 1867 by August Wilhelm von Hofmann, a German chemist who developed formaldehyde, a chemical that was able to penetrate into the pores of the skin and tissue and preserve them without causing significant alteration in color or structure. Other embalming chemicals, mixtures of preservatives, sanitizers, and disinfecting agents, that have been used over the years include formaldehyde (5–30 percent) combined with methanol, ethanol, and other solvents. Arsenic had been used as an embalming agent, but it was banned in 1910 because of concerns that morticians could be sickened by its use or that cases of deliberate arsenic poisoning would not be detected.

In addition to embalming, burial practices in many cultures require that the body be placed in a coffin or casket to help isolate it from the environment and slow the rate of decay. The coffin or casket is placed, in turn, inside a concrete vault or burial chamber, which is intended to protect it from the crushing effect of the overlying soil. Both the coffin and vault slow but do not prevent the entrance of decaying microorganisms and water or their contact with the body. Both of these customs, embalming and coffin burial, while offering comfort to the living and protecting public health, also protect local environmental quality in the long term.

### GROUNDWATER IMPACTS

Infiltration of rainwater into and through the soil and the movement of groundwater are natural processes that affect buried remains. These infiltrating fluids

can interact with the remains, dissolve chemical compounds, and form a leachate that can interact with other water. Contaminants potentially associated with cemetery leachate include elevated levels of formaldehyde and other preservation chemicals, sulfate, nitrate, and pesticides (from landscaping operations), formalin chemical (also used in tissue preservation), elevated bacterial counts, and chemical oxygen demand (COD). Cemeteries often are located on well-drained local hilltops that serve both as recharge areas and as spring sources for many streams. Many are old, in use since the 1800s or earlier, and have provided ample opportunity for groundwater to have contact with embalming chemicals. It is surprising that there have been few documented cases of cemeteries' contaminating surface water or groundwater.

Arsenic detected in groundwater sampled down-gradient of a Civil War cemetery in Virginia may be related to arsenic-based embalming fluids used during the late 1800s. Other examples from the almost 100,000 named cemeteries in the United States are rare. This is because most people, even those who do not have a meaningful science or public health background, know better than to establish a cemetery in an area where leachate charged with embalming chemicals and bacterial decomposition products can degrade local groundwater supplies. Land use patterns also play a role in minimizing groundwater effects from cemeteries.

In urban areas, where burial densities are high, most communities are connected to municipal water systems, where supply sources are far removed from human and, in many cases, animal burial grounds as well as other contamination. In rural areas, people are well aware of the need to keep a safe distance between their source of drinking water and the decaying remains of their loved ones. For example, in Wisconsin it is illegal to drill a water supply well within 1,000 feet (331 m) of a cemetery. In parts of the country where water tables are close to the surface such as along the Gulf Coast, bodies are interred in above-ground vaults or tombs. St. Louis Cemetery 1 in New Orleans, commissioned in 1789, was one of the first cemeteries in the United States to utilize aboveground burial and is a popular tourist attraction.

Annually, burial of the dead in the United States consumes more than 30 million board feet (9.2 million m) of hardwoods (for caskets), 110,000 tons (100,000 metric tons) of steel, 3,000 tons (2,727 metric tons) of copper, 1.6 million tons (1.45 million metric tons) of

*(continues)*

(continued)

concrete, and almost 830,000 gallons (3.15 million L) of embalming fluid. Studies are ongoing to improve quantification of potential impacts on groundwater of embalming chemicals and the decay of casket materials. Recently, most mortuaries have switched from formaldehyde as the embalming fluid of choice to more environmentally friendly chemicals such as aardbalm, an iodine-based product.

As environmental awareness has grown, however, so has the demand for natural, or "green," burial. In this type of interment, the body is not embalmed, although it may be washed, disinfected, or religiously anointed. It is placed in a cloth shroud or a biodegradable box, not a wooden or metal casket or concrete vault, and placed in a grave in direct contact with the soil. All this is done to speed the process of decay and allow the remains to be absorbed or returned more quickly to nature. Natural markers such as trees and shrubs are planted to mark the gravesite, and neither pesticides nor irrigation methods are used to preserve the landscaping. Modern geolocating devices, such as global positioning systems (GPS), record and keep track of each burial plot. The open green established by these types of cemeter-

ies provides important, very usable ecological habitat and can serve as a wildlife preserve.

*See also* ARSENIC; LEACHATE; FORMALDEHYDE; PESTICIDES.

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by Robert P. Blauvelt

do not degrade into another chemical, the organic compounds may be degraded by microorganisms if the chemical is not toxic to them. In contrast, soluble compounds dissolve into the water and exist in that form until they are degraded. Degradation may be by biological or chemical processes, or the chemical may simply evaporate from the water surface. Chemical degradation may be by oxidation at the surface, reaction with other chemicals in the water, or photolysis by exposure to sunlight.

Releases of pollutants into surface water can be divided into point source large-volume spills and nonpoint source long-term low-volume releases. The large-volume spills are commonly reported in the media and are ecologically devastating to a restricted area. The long-term low-volume releases happen imperceptibly but can cause global-scale problems.

### Large-Volume Spills

The most infamous type of large spill by its catastrophic nature and huge volume is an oil spill. Oil spills typically involve both human and wildlife casualties and are well reported in the media. The photos of these incidents can be quite spectacular. There are two main types of spill: those from production facilities through blowouts or sabotage and those from transportation accidents. Although transportation

incidents are more numerous and spectacular, the production facility spills are much larger and more serious. The 1969 Santa Barbara, California, blow-out and spill were galvanizing events in the early American environmental movement. The images of wildlife covered in oil and dying on television every evening turned the sympathy of the nation toward environmental concern.

Santa Barbara was a relatively small spill compared to the huge 1979 Ixtoc 1 spill in the Gulf of Mexico, but it occurred in the deep ocean in Mexican waters, and the slick took a long time to reach the Texas coast. This spill also caught the attention of the American public but not the way Santa Barbara did. Ixtoc released more than 3 million barrels (140 million gallons [532 million L]) of oil into the Gulf of Mexico; by comparison, in the Santa Barbara spill, approximately 3 million gallons (11.4 million L) of oil spilled into the Pacific Ocean. The 2010 *Deepwater Horizon* disaster had aspects of both Santa Barbara and Ixtoc I: It spilled a huge amount of oil into the Gulf of Mexico (204 million gallons [772 million L]) and captured the attention of the American public. It was the greatest environmental disaster in U.S. history.

The largest release of oil was caused by the 1990 Desert Storm oil fires in Kuwait. When American

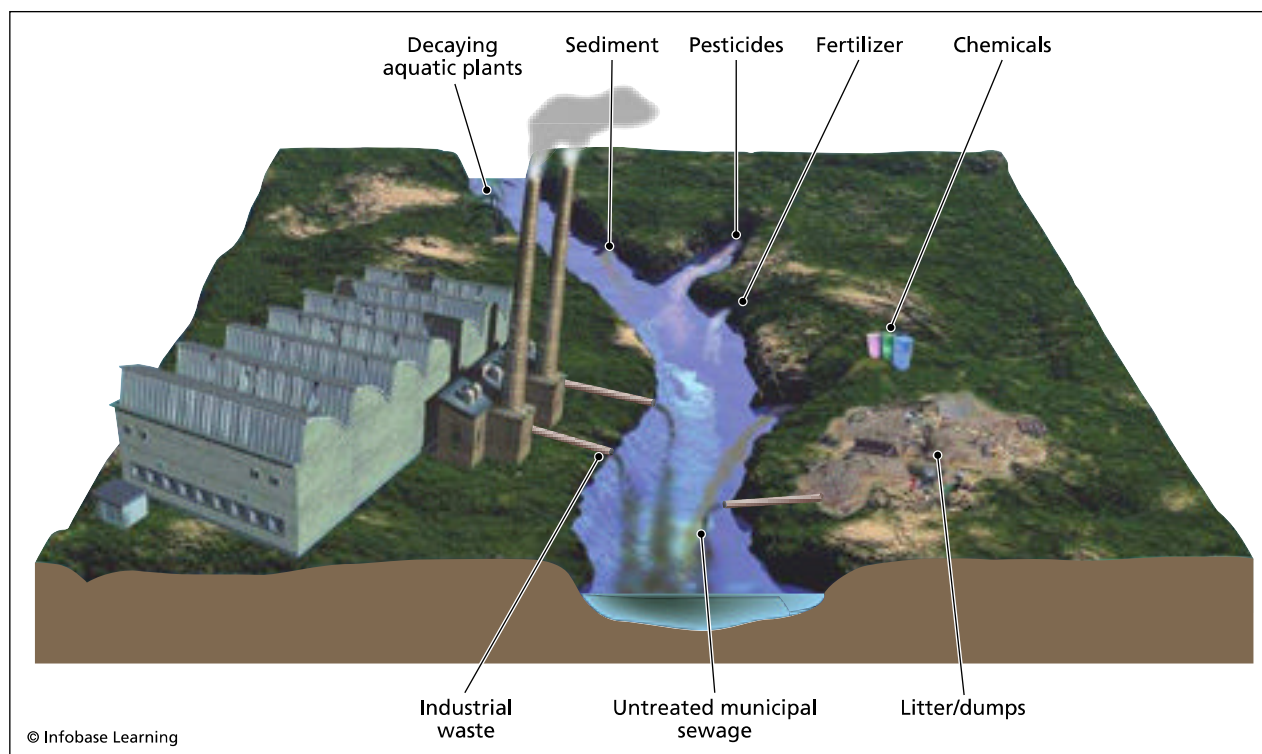
troops invaded Kuwait to drive back the invading Iraqi troops, during their retreat, the Iraqis blew up as many of the wellheads from producing oil wells as they could. The result was a phenomenal conflagration and spill that would take months and the latest technology to control. It is estimated that the oil slick created by the release of an estimated 5.6 million barrels of oil (250 million gallons [50 billion L]) from coastal terminals and land-based oil wells contaminated a 300-mile- (483-km-) long stretch of beach. The oil was spilled through a combination of sabotage of the fields by the Iraqis, bombing, and a major battle site at a refinery. With so much oil in such a restricted area, it is estimated that the local ecology will never recover.

Spills during transportation occur primarily during shipment in tankers and supertankers; spills during transfer and from pipelines are less common and normally less damaging. There have been numerous accidents but none more infamous in the United States than the 1989 *Exxon Valdez* disaster. The supertanker *Exxon Valdez* hit a reef in Prince William Sound, Alaska, tearing a large gash in the hull and spilling 35,000 tons (10.8 million gallons [40.8 million L]) of oil into the pristine waters. The spill spread quickly to cover more than 900 square miles (2,300 square km) and caused great damage to the

fragile arctic ecosystem. As it turned out, the captain of the tanker was intoxicated at the time of the accident. This incident initiated great changes in the industry, especially with regard to tolerance of alcohol and drugs.

There were other incidents that were just as damaging, and many were handled just as poorly. The first accident with a supertanker was the *Torrey Canyon* spill off the southern coast of the United Kingdom in 1967. There was no protocol for tanker accidents, and numerous mistakes were made, the worst of which was to bomb the wreck with Royal Navy aircraft in an effort to sink the vessel and ignite the oil. There is still unexploded ordinance in the area today. Another example of igniting oil to remove the slick from a tanker spill was the 1992 wreck of the supertanker *Aegean Sea* off the coast of Spain. Upon ignition, the slick became an inferno. Flames shot 164 feet (50 m) high into the air, and oil residues coated the Tower of Hercules, a 1,900-year-old Roman lighthouse that is still in active use some 1.6 miles (2.5 km) outside the city of La Coruña, Spain.

In addition to the numerous oil spills from tanker accidents, there have been many catastrophic chemical spills to surface water. One of the more recent and important examples occurred in Jilin, China, in 2006. An industrial spill on the Songhua River



**Illustration showing several types of point source (chemicals, dumps, sewage, industrial waste) and nonpoint source (sediment, pesticides, fertilizer, decaying plants) pollution that can affect surface water quality**



contained several organic compounds but was primarily benzene. The residents of Jilin could not drink tap water for several days, and many people became ill because of the fumes. The importance of this spill is that the Songhua River flows into Russia, and the spill created an international incident. Fortunately, the spill occurred in winter, and cold weather slowed and dispersed the pollutants, allowing enough time from the release until it reached the border to resolve the situation diplomatically.

No matter how impressive these catastrophic incidents are in terms of impact on the environment and public health, they pale in comparison to the long-term, low-volume releases in terms of both total amount of pollutant released and long-term effects.

### Long-Term Low-Volume Releases

By far, most surface water pollution is the result of multiple or regular low-volume releases over a long period. These releases are not generally dangerous individually, and the pollutants may be absorbed by the system, dispersed, or biodegraded before they become a problem. After numerous releases, however, the surface water system eventually becomes overwhelmed and becomes polluted. The pollution may be released by a single facility or multiple sources. In the case of the Hudson River, New York, the source was a single facility. The General Electric plant in Fort Edward and Hudson Falls, New York, manufactured capacitors using polychlorinated biphenyls (PCBs) in the process. PCBs are organic dielectric fluids that produce a number of serious adverse health effects in humans, including cancer. They dumped PCB-laden wastewater from manufacturing directly into the Hudson River. The U.S. Environmental Protection Agency (EPA) and General Electric Inc. estimated that about 1 million pounds (453,592 kg) of PCBs was released into the Hudson River system south of Fort Edward over the 30 years 1947–77. This 200-mile (320-km) stretch of the Hudson River is now the largest single area of a Superfund site in the United States.

The Cuyahoga River in Cleveland, Ohio, is an example of multiple sources of pollution affecting a single surface water body. There have been numerous manufacturing, storage, and transport facilities along the river within and near Cleveland for well over a century and a half. These companies regularly disposed of their solid and liquid waste by dumping it into the river. The slow-moving river became so choked with pollution of oil and debris that it regularly caught fire. Its first recorded fire occurred in 1868. Ironically, the most infamous fire occurred in 1969; it was ironic because the fire was not very big

and the city had already devoted funds to cleaning up the river. It occurred, however, when the environment had become a major concern among the American people because of environmental disasters such as the Santa Barbara oil spill.

## GROUNDWATER POLLUTION

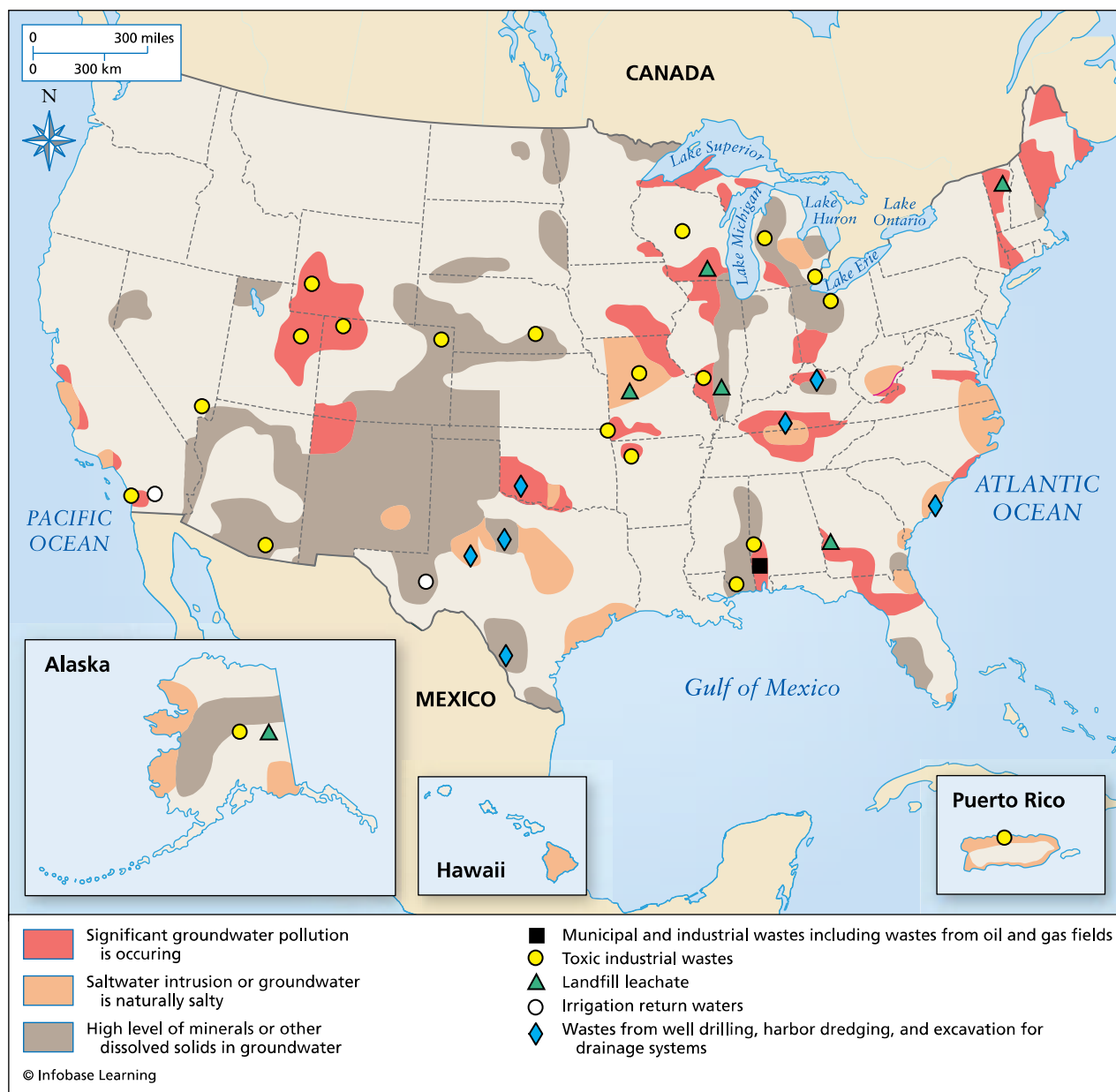
Groundwater pollution is primarily the result of leaking point sources, although there are situations when nonpoint sources may contribute to or even be the entire source. Pollution is also primarily the result of human activities, but in a few serious cases it is natural. It can also be a mix of the two. Groundwater pollution is usually dissolved into the groundwater and contained within rock or soil. The particles and water tend to dilute the pollutant to much lower concentrations than is found in surface water. The exception to this is in waste injection wells, where concentrated waste is injected as a slug directly into an aquifer. LNAPLs in groundwater tend to float atop the water table and remain relatively concentrated, whereas DNAPLs may mix with groundwater and become diluted more easily.

Certain geological configurations may also increase the concentration of the pollution. There is a configuration called bathtubting in which there is a bowl-shaped subsurface depression in an impermeable layer, most commonly clay. There is no flow of groundwater from the outside and, therefore, no migration and minimal dilution. If this depression is capped with a layer of clay, the pollutants can remain isolated from the environment indefinitely. If it is not capped, infiltrating meteoric water can overfill the depression, and the pollutant can rise to the surface and overflow the bathtub. Fractured rock aquifers can also become concentrated with pollutant by forcing out the groundwater. The fracture acts as a pipe, and if the pollutant is not soluble in water, it can provide enough pressure to expel the water and thoroughly replace it.

Although many environmentalists would rather blame all pollution on humans, a significant amount of groundwater pollution is natural. Certain pollutants can be natural while others have only human sources. They also have a completely different character in terms of source and dispersal. It is for this reason that they are considered separately.

### Natural Sources of Groundwater Pollution

In some cases, the natural rock and soil in an area can contain excessive levels of a pollutant. Certainly, mining prospects contain high concentrations of target metals or other elements, so the groundwater in the area will also probably be enriched. If the



**Map of the United States showing areas with significant groundwater pollution problems and the sources of that pollution**

target elements are heavy metals, the groundwater can be hazardous. Luckily, most heavy metals are not water-soluble and tend to be immobile unless the groundwater is quite acidic. These metal deposits are typically in crystalline rocks (igneous or metamorphic), and they are relatively restricted in extent.

One quite famous case of naturally occurring inorganic pollutants in sediments spread over a large area is in Bangladesh. Odd arsenic-rich sediments underlie large areas of the country. Prior to the 1970s, they were not a problem because most citizens employed surface water for personal use. The

problem was that there were frequent outbreaks of waterborne disease. The United Nations began an effort to eliminate the disease by encouraging the installation of tube wells for drinking water. It was only after this effort that the health problems began. The poisoning has been severe and has produced many serious adverse symptoms, including blackfoot disease, affecting large amounts of the population. It is estimated that 35–77 million residents of Bangladesh are at risk for arsenic poisoning.

A situation of enhanced natural groundwater pollution is occurring in New Jersey. In central and

southern New Jersey, residents draw their water from the sediments of the Atlantic Coastal Plain. Several years ago, during routine testing, several water samples tested positive for mercury. After a survey, a total of 600 wells were found to have elevated levels of mercury. The problem was that there were no nearby sources for the pollution such as landfills or manufacturing plants. With more detailed study, it was found that infiltrating water in the area was rich in residues of agricultural fertilizers. Apparently, when the infiltrating water encountered a common mercury-rich clay, exchange reactions released the naturally occurring mercury into the acidic groundwater. This example is really an interaction of natural pollution with groundwater pollution from humans.

### Groundwater Pollution from Humans

The natural sources of groundwater pollution are rare. Leaky landfills, buried waste, and underground storage tanks (UST) are far more common and dangerous sources. Perhaps the best example of polluted groundwater from buried waste is Love Canal in Niagara Falls, New York. The pollution was dumped into a bathtub configuration in impermeable clay by Hooker Chemical in the late 1940s to early 1950s. The pollutants included all of the most dangerous organic pollutants such as dioxin, polychlorinated biphenyl (PCB), trichloroethylene (TCE), pesticides, and numerous others. It was one of the largest repositories of hazardous waste in the world. The company installed a solid clay and ceramic cap, and there were no leaks for many years. The problem was that the city of Niagara Falls decided to develop the property. This situation might have even worked out well except that the city breached the cap when they installed sewer and water lines. The holes in the cap allowed precipitation to infiltrate into the toxic waste, and, as a result, it filled up the bathtub. Boils of toxic waste began appearing in the yards of residents, and children were receiving severe chemical burns while at play. When reports of the situation were on the evening news in the mid-1970s, Love Canal became the battle cry for the environmental movement and the new idea of the Superfund was born through attempts to address the problem.

Less dramatic and severe incidents of groundwater pollution are addressed on a daily basis by the huge environmental consulting industry. There are plumes of groundwater pollution from leak underground storage tanks (USTs) at gas stations and dry cleaning facilities in every state if not every town in the United States. Leaky septic systems and old landfills further degrade the quality. The shallow groundwater quality in virtually every urban area in

the country is so poor that it is not potable and often it is dangerous. In order to obtain clean groundwater in most areas, deep wells are required. The quality of water in America is in a near-crisis situation.

See also AEGEAN SEA OIL SPILL; AQUIFER; ARSENIC; COASTAL PLAIN DEPOSITS; CUYAHOGA RIVER POLLUTION; DIOXIN; EXXON VALDEZ OIL SPILL; HUDSON RIVER PCB POLLUTION; INORGANIC POLLUTANTS; IXTOC I OIL SPILL; KIRKWOOD-COHANSEY AQUIFER; LANDFILL; LOVE CANAL; NEW YORK CITY, AIR QUALITY OF; MERCURY; ORGANIC POLLUTANTS; PCBs; PESTICIDES; SANTA BARBARA OIL SPILL; SUPERFUND SITES; TCE; TORREY CANYON OIL SPILL; UNDERGROUND STORAGE TANK; WELLS.

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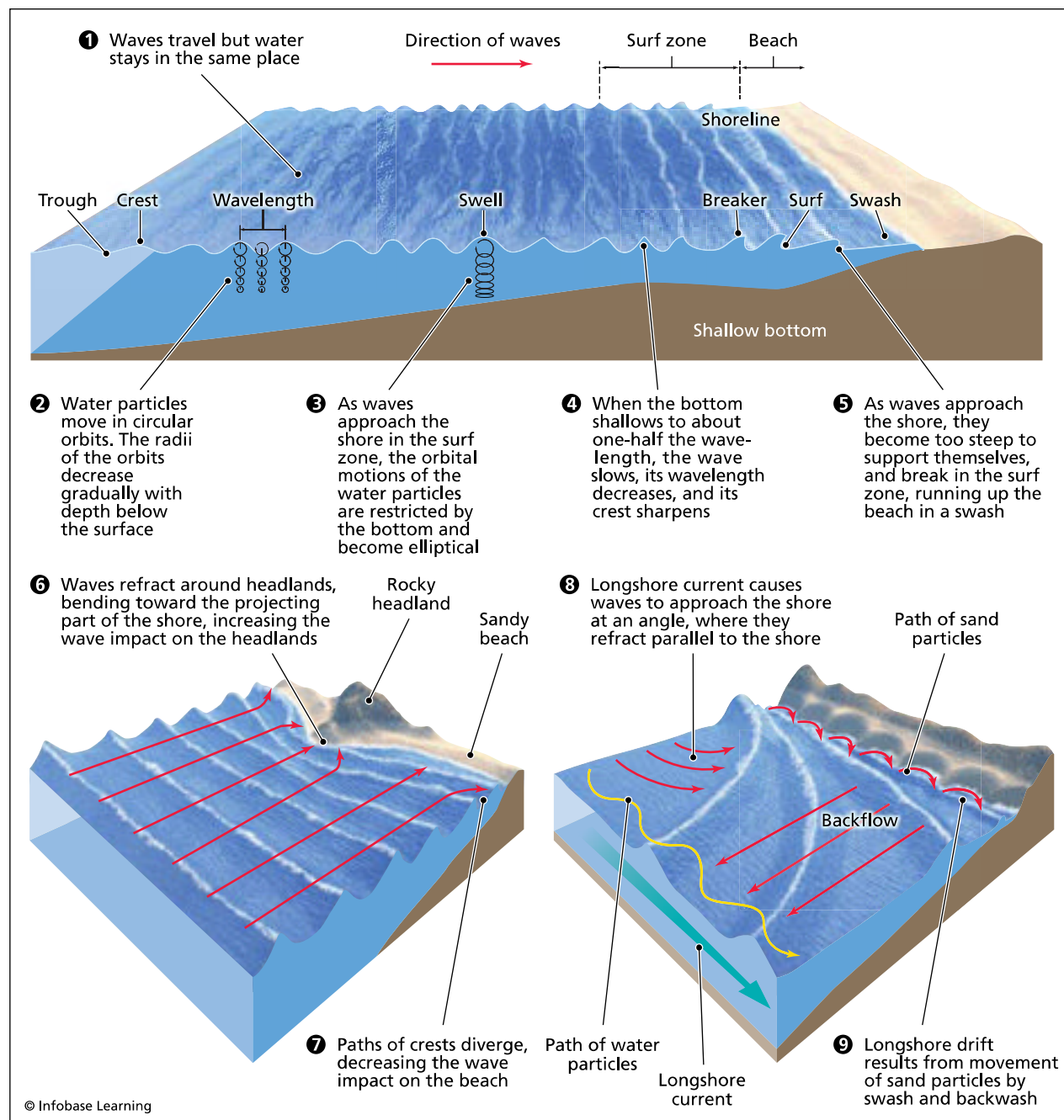
**waves** Ocean waves occur throughout a basin but are most noticeable at the shoreline. Driven by winds, they travel across the surface of the water. The greater the distance that the wind may act upon the surface, the greater are the resulting waves. This distance of interaction is called the fetch. Intensity of winds also determines wave height. Ocean waves form a sinusoidal pattern on the surface with all the features of those studied in physics. The peak of the wave is the *crest*, the bottom is the *trough*, and the distance between peaks or troughs is the *wavelength*. The height of the wave is the difference in elevation between the crest and the trough, and the amplitude is one-half of the height. The speed of the wave is typically measured in its *period*, which is the time it takes for similar points on two adjacent waves to pass a reference location.

Even though waves move consistently across a basin, the water in the basin generally remains in a fixed location regardless of the waves. In the open water, as a wave moves through, water particles move in a circular motion that is retrograde

to wave propagation. This means that as the wave approaches an area, the water is first pulled out to sea before lifting, falling, and returning to its original position as the wave passes by. This circular motion of the water particles is called an orbital, and they are larger nearer to the surface. The depth to which the wave penetrates is equal to one-half of the wavelength and is called the wave base. Below this, the water is still. Wave base constantly shifts up and down with the tides, being deeper in the basin at low

tide and shallower at high tide. It has a greater range during spring tide and the least range during neap tide. Wave base also varies seasonally with larger winter waves penetrating much deeper than gentler summer waves. Storm waves also produce a much deeper wave base.

As the wave approaches the shore, the wave base makes contact with the seafloor. The dragging of the wave on the seafloor slows it down, especially at the base. The wave begins to tilt forward and rise



Block diagrams showing shoreline processes as the result of the waves' approaching the shore and breaking at the beach



up. Successive waves crowd together as the result of the slowing. The orbitals of water movement flatten and the wave becomes asymmetric. It finally falls over in the breaker zone, and the momentum of the wave pushes the water up the shore face in the swash zone. It is the interaction of the waves with the seafloor that moves sediment. Gentle waves have shallow wave bases and do not have the energy to keep sediment in suspension. Sand can, therefore, deposit closer to the shore, and, in general, beaches grow wider in the summer as a result. In the winter, the waves are more energetic and have deeper wave bases. They can scour out sand and keep it in suspension. Energy is not low enough for deposition for up to several hundred yards offshore. In winter, sand is consequently removed from the beach and stored in offshore sandbars. There is a constant cycle as sand is slowly moved to the beach in summer and quickly removed to the offshore during the winter.

### LATERAL CURRENTS AT THE SHORE

Waves commonly do not move straight toward the shore but instead approach it at an angle. As a result, there is a net lateral movement of water parallel to the shore in the direction of the acute angle with the shore that is pushed by the waves. This lateral movement of water is called the longshore current, and it varies with the angle of approach. The more oblique the wave, the stronger the longshore current. This angle of approach typically only changes during storms, but in local areas it may vary with tides as well. As the wave approaches the shore, it drags on the seafloor and slows. The leading edge of oblique waves slows more than that part of the wave that angles out into deeper water. This difference in speed causes the wave to bend as it approaches the shore, a phenomenon called wave refraction. For shorelines that are not straight, the bending of the wave as it approaches the shore can be quite complex. In some cases, longshore currents can be driven toward each other, forming a temporary buildup of water. This built-up water is gravitationally unstable and escapes out to sea in a rip current, which can be dangerous for swimmers. It can also move large amounts of water and the accompanying pollution long distances away from the shore and out to sea.

### Littoral Drift

The longshore current typically transports sediment along the coast as littoral drift. The motion of individual sediment particles is not straight along the shoreline but instead resembles a sawtooth pattern. Particles move toward and away from the shore with each successive wave in addition to the lateral movement. Thus, the sand moves down the beach with

time. It is for this reason that beaches have been referred to as rivers of sand. Littoral drift can extend the length of a barrier island if the angle of the waves to the shore remains relatively constant. In this case, the barrier island continues to grow in length in the direction of the littoral drift. This growth can create problems if it crosses a channel or shipping lane.

If the angle changes abruptly or there is an obstruction, the sand may pile up in one area or be removed from another. Uneven coastlines typically have interspersed areas of sand buildup and starvation, which create difficulties for beach management efforts. The same problems arise when beach residents build jetties, piers, and breakwaters in front of their property. The flowing sand tends to be blocked by jetties and builds up on the side facing the littoral drift. The longshore current removes sand from the downflow side of the jetty, thus producing a sand deficit. As a result, shorelines with jetties have a scalloped appearance. Breakwaters are designed to reduce the energy of the waves reaching the shore. The reduction of energy allows sand to deposit behind the breakwater, where it normally would have continued to be transported by the longshore current. The beach slowly advances out to the breakwater, creating a spit of land. In simple cases, the littoral drift continues around the spit once it has formed. In complicated cases, the longshore currents can be changed, with potential to alter the whole sediment budget of the beach.

### SAND REPLENISHMENT PROJECTS

The combination of dams on coastal rivers, which reduce the sediment supply to the beach, and faulty beach management programs may cause a deficit of sand on certain beaches. Many beach communities rely on income from tourism to survive, so they must undertake efforts to replenish the sand supply. In many cases, the federal government is involved and funds the costly replenishment projects so the community is spared the cost. The sand that is stored in bars offshore during the winter may not fully return during the summer and over time accumulates there. The main replenishment technique, in this case, is to pump the sand back to the beach from offshore barges. In most instances, there is no problem with the practice unless offshore pollution is encountered by the barges. Then the pollution, whether dumped waste, ordinance, or settled chemical spills, can be placed in a location where people can have contact with it. There have been many serious incidents where medical and other waste has washed onshore, causing great concern. Old ordinance has also wound up in beach sediments. It is just a matter of time before one of these incidents turns into a disaster.

See also BEACHES; CONTINENTAL SHELF; HURRICANES AND POLLUTION.

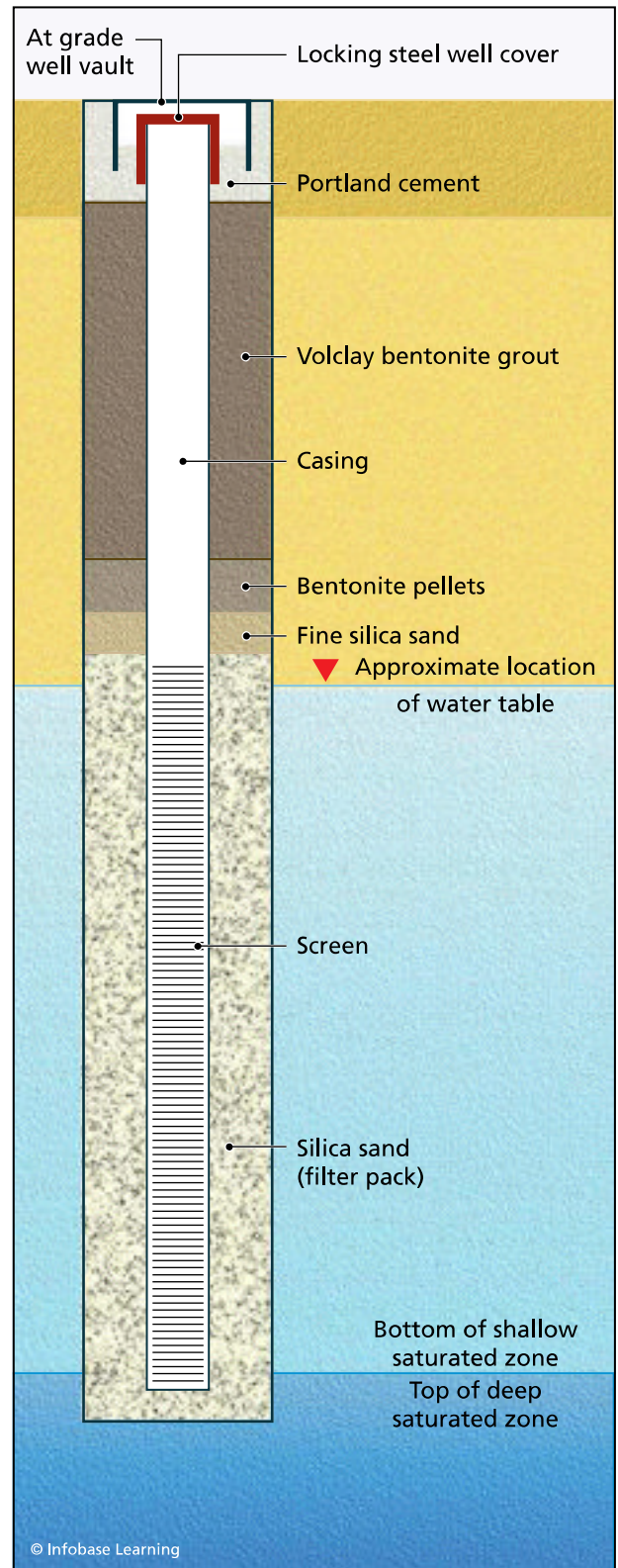
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**wells** Any hole dug or drilled into the ground is a well. They can be as shallow as a few feet or as deep as 6 miles (10 km) or more. Wells can be used to test or remove water, rocks, and minerals or oil and gas. They are drilled using cable tools, which drive holes into the ground by repeated pounding of a weight if the well is in relatively soft, but consolidated material, and is relatively shallow (hundreds of feet). Rotary drilling rigs bore wells into virtually any kind of material and can extend to great depths (thousands of feet). There are a variety of bits on rotary rigs depending on the type of material to be drilled. They are capable of taking full-bore core samples of the rock and sediment that they penetrate, even in solid crystalline rock by using a diamond bit. Depending upon the material drilled and the depth, many wells must have casing set in part or all of the depth of the well. Casing is a sleeve or pipe mainly made of steel and must be cemented into place to seal the shallow fluids and sediments from entering the well bore. The most complex of these wells are for oil exploration and may take many months to drill and complete. In shallow wells, the casing may be plastic, cast cement, or ceramic. For environmental purposes, the most common wells are injection wells, monitoring wells, test or delineation wells, and recovery wells.

### TEST, OR DELINEATION, WELLS

Just as the name suggests, test wells are drilled simply to determine the subsurface composition or conditions. Test wells may be drilled to extract a sample of soil, gas, or fluid or to measure some physical or chemical parameters of it. For environmental purposes, they may help to delineate the extent of contamination from a source. In this case, a sample of fluid must be extracted by following a strict protocol.



**Diagram of a typical monitoring well used in a project to address an underground pollution problem**

Delineation wells are most commonly drilled to delineate an underground pollutant plume within an aquifer. They are drilled in stages, first to perform

a reconnaissance study of the degree of pollution and to determine the direction of groundwater flow. Once the preliminary study is complete, a drilling plan is established to define the problem best. The intricacy of the plan depends upon the extent of the plume, the sensitivity of the area around the plume, and the plume pollutant or pollutants. Larger plumes require more wells, as do areas that are environmentally sensitive or have dense human population. Hazardous wastes may also require special planning to minimize exposure of the community and workers. Delineation wells and the analysis of their results form an essential part of the remediation plan for the pollutant, the next step in the remediation process.

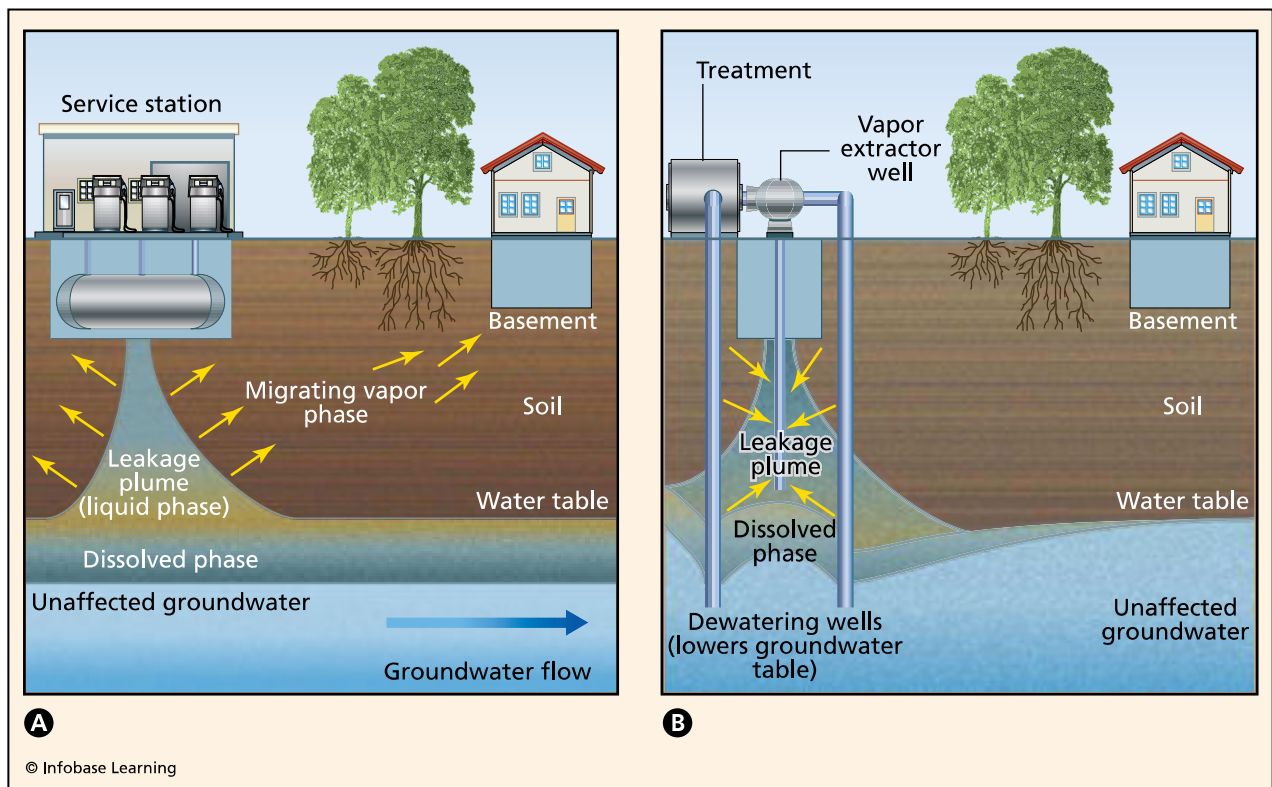
Delineation wells must also be drilled for subsurface soil pollution. In this case, there is no determination of groundwater flow direction to guide the drilling plan. Instead, drilling may have to be done in a grid pattern to delineate the pollution unless some other information on disposal is available. Such a drilling plan will show the areal extent of the pollution and at least part of the range of concentrations of pollutants.

### RECOVERY WELLS

Once a polluted groundwater plume is delineated, it must be remediated. In most cases, remediation can be done by pumping out the polluted groundwater and treating it once the source of pollution has been removed. Recovery wells continuously pump wastewater from the ground. Depending upon the size, extent, and migration of the pollutant, in some cases, a few wells or even one well may suffice. In the case of an extensive pollutant, a line of overlapping pumping wells can form a barrier to groundwater flow. The depth of penetration of the well or depth at which it is screened determines the horizon at which the water will be pumped and removed. There are many other configurations of well placement and screening levels to remove pollutants from the groundwater depending upon the plume and pollutants.

### INJECTION WELLS

Any well in which fluid or gas is driven down into the ground is considered an *injection well*. The most common injection wells function as waste disposal sites, and their driving mechanism is grav-



**Diagram that shows a gasoline leak from an underground storage tank (UST) migrating to the water table and releasing vapor into the soil gas (A) and a potential remediation method using two types of wells (B). The dewatering wells pump out the liquid and contaminated groundwater for treatment as well as lowering the water table in overlapping cones of depression. This leaves the gasoline in the soil, where it can evaporate, and the vapor is removed using an extraction well.**



ity. Probably the most common injection well in the past was a dry well. Attached to most old houses was a shallow (three to four feet [1–1.2 m]), typically rectangular well into which a drainpipe emptied. These wells were dug for “gray water,” wastewater from the bath or washing machine, to extend the capacity of the septic system with little danger of contamination. When the wastewater was drained into the dry well, the level was well above the water table and gravity forced the wastewater into the soil below the well, where it would be purified before infiltrating the groundwater system. If the homeowner was careful, the system worked reasonably well.

The same dry well concept was unfortunately also used in many small businesses and even in major industry. In small companies, a pit may have been dug on the premises into which all liquid waste was dumped. In a mechanic shop, old oil and solvents may have been dumped into a dry well only to pollute the groundwater in the area. Injection wells of this type cause severe environmental damage.

High-pressure injection wells are of various types for different purposes. Deep injection wells are utilized for burial of high-level waste at levels below the aquifers that provide water for public use. In the Rocky Mountain Arsenal in Colorado, high-pressure waste injection triggered earthquakes and had to be shut down. Other high-pressure injection wells are used to enhance fluid and gas flow around the wells. The high-pressure fluid fractures the rock around the well in a process called hydrofracturing. Both water wells and oil wells can produce higher yields as a result of this method. Even high-pressure gas can be used to fracture soils for the same purpose. This process is called pneumatic fracturing.

Injection wells may also be used to remediate pollutant problems. Chemicals and/or microorganisms may be pumped into the subsurface to address the pollutant. The microorganisms are used for bioremediation of the pollution problem.

*See also* AQUIFER; BIOREMEDIATION; IN SITU GROUNDWATER REMEDIATION; ROCKY MOUNTAIN ARSENAL; SEWAGE TREATMENT PLANTS.

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**wetlands** After a history of considering wetlands a nuisance and draining and filling them whenever possible, today many communities and elected legislative agencies almost revere them. A number of laws and acts on the local, state, and federal levels have been passed to protect wetlands in numerous areas. The presence of wetlands formerly prevented development because they were too difficult and expensive to build on. Now they prevent development because they are considered to be ecological and environmental necessities. The biodiversity in a wetland and its position as the gateway between surface water and groundwater make them invaluable. Their ability to sequester carbon and toxicants that would otherwise be released to the environment and to store potentially usable fuel (peat) are other functions that are typically not even considered but add to their value.

Wetlands are areas of land that are inundated by water to a depth of one inch (1.64 cm) for at least several days in most years. There are three factors that determine the presence of wetlands: wetness (hydrology), the type of vegetation, and the type of soil. The most difficult of these factors to document is wetness because it can be so short-lived. The soils and vegetation, however, are characteristic and develop even if the area is wet for a short time. They are commonly used to determine wetlands even without the water. Wetlands have several



**Wetlands in British Columbia, Canada** (Vera Bogaerts; used under license from Shutterstock, Inc.)

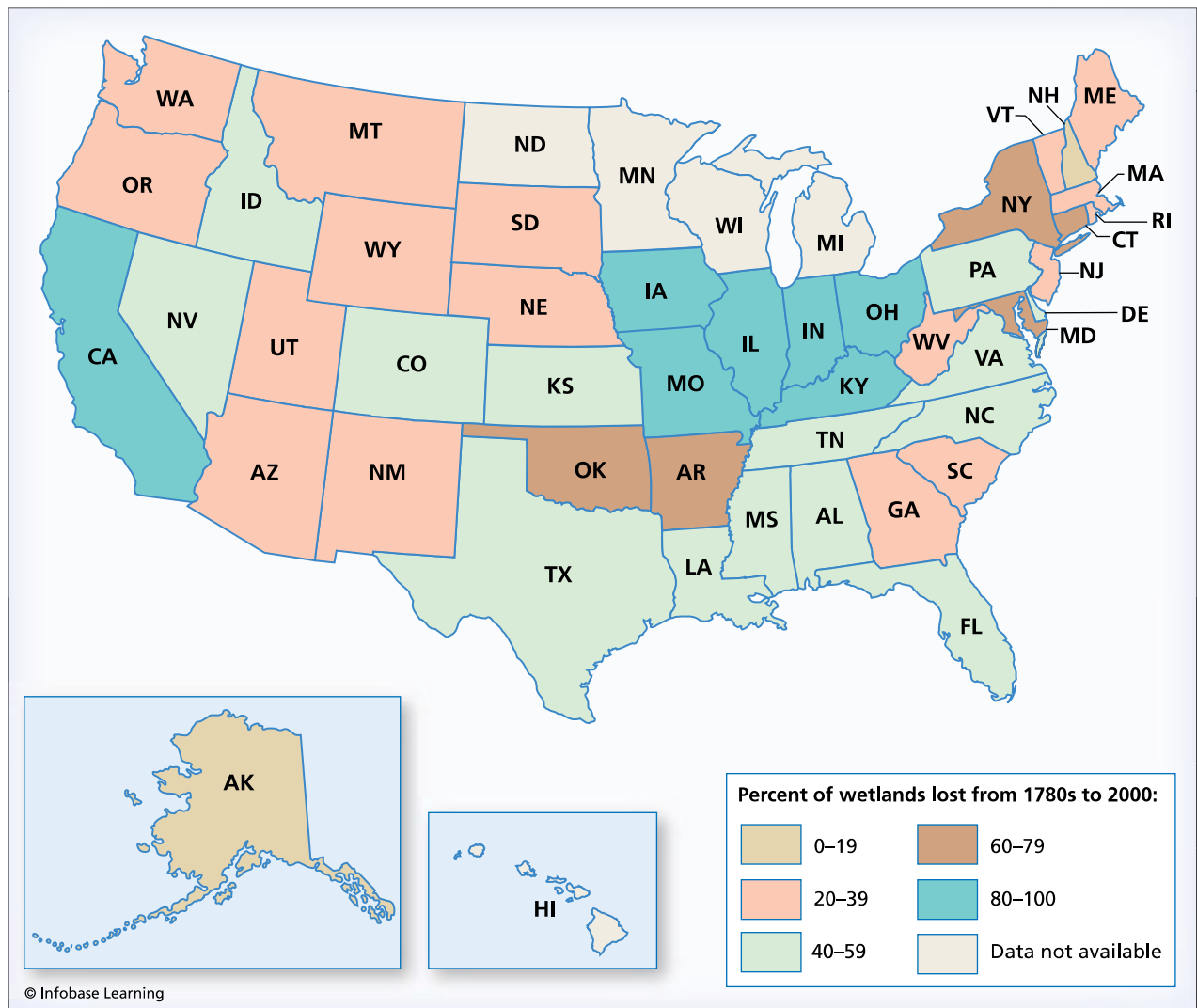


landscape features, including marshes, swamps, bogs, prairie potholes, and vernal pools, among others. Swamps and marshes are both frequently or continuously inundated by water; swamps have less flow. Bogs are wetlands that accumulate peat deposits through characteristic vegetation. Prairie potholes are small marshlike ponds, and vernal pools are shallow depressions that only occasionally hold water.

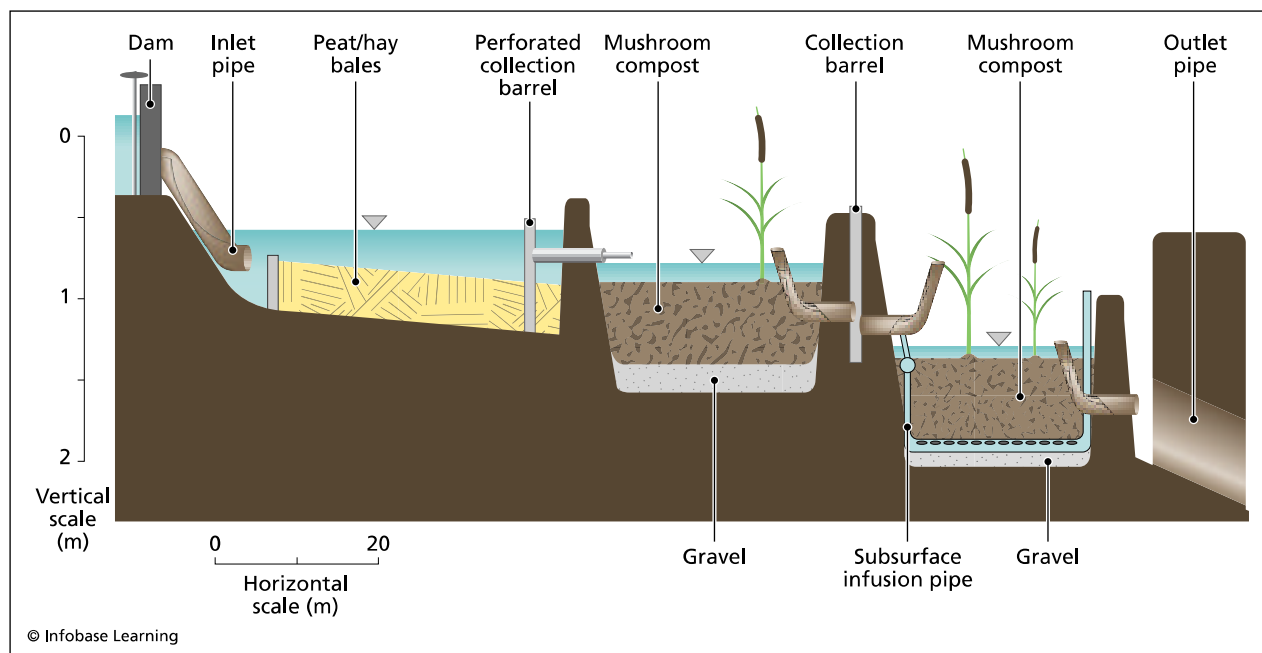
Wetlands and the ecosystems that they contain serve important environmental functions. Wetlands in coastal areas, salt marshes, for example, form buffers against coastal erosion by storm waves and floods. Plants in wetlands act as natural filters, trapping sediment, nutrients, and pollutants and preventing them from entering surface water supplies. Freshwater wetlands function as natural water storage areas during floods, thus reducing the severity

of downstream floods by allowing slow release of water. Wetlands are typically highly fertile areas, rich in nutrients and providing habitats for a variety of plants and animals. Freshwater wetlands often act as aquifer recharge zones, thus supplying groundwater to regions.

Coastal marshes are almost entirely protected by legislation in the United States. Freshwater wetlands are following suit in most areas but still threatened in many others. Approximately 1 percent of the nation's total wetlands is lost every two years and nearly all are freshwater varieties. It is estimated that about half of the total wetlands in the United States have disappeared in the past 200 years, including about 90 percent of all freshwater wetlands. They have been drained for agricultural purposes or urban development. Public concern over these losses has sparked efforts to restore nat-



Map of the United States showing the percentage of wetlands purposefully destroyed in each state between 1780 and 2000



**Diagram of constructed wetlands for the remediation of wastewater with input, left, and exhaust, right—a series of settling ponds/swamps remove pollutants through surface bioremediation.**

ural wetlands, but these projects are few, expensive, and not always effective.

In contrast, in some coal-mining areas, artificial wetlands have been constructed to reduce the effects of acid mine drainage cheaply and effectively. In these areas, vegetation that can tolerate high acidity and sequester inorganic pollutants is planted in a permanently wet catchment basin. The closed basin holds the pollutants until the plants can uptake them. The carbon sequestration capacity of wetlands may play an important role in reducing atmospheric greenhouse gases in the future. It is probably the easiest and most effective method of addressing the problem. As other uses of wetlands are identified for restoration of environmentally damaged areas, this practice may increase our wetlands in the future.

See also ACID MINE DRAINAGE; AQUIFER; INORGANIC POLLUTANTS.

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**Woburn wells G and H Woburn, Massachusetts (1983–present) Water Pollution** The pollution from the Woburn, Massachusetts, site was no more remarkable than that of many other polluted sites, but the situation is probably one of the best known among Americans. The reason is that the resulting lawsuit and the events leading up to it were popularized in both a book in 1995 and the 1998 film, *A Civil Action*. Although the location, names, and some of the facts were changed for the sake of protection of the victims as well as enhancement of the melodrama, the basic situation is preserved in the popular version. Some of the overlooked details, however, are interesting in their own right with regard to the pollution.

#### BACKGROUND

Tanning, as the process of turning animal skin into leather is commonly known, involves reacting collagen fibers in the hide, most commonly of cattle, sheep, or pigs, with a special chemical agent. Collagen is a type of tough, fibrous protein that is present in bone, cartilage, tendon, and other connective

tissues. In the United States, the most common tanning agents are trivalent chromium and vegetable tannins extracted from certain types of trees. Other agents, depending upon the intended use of the final product, include alum (potassium aluminum sulfate dodecahydrate, or potash alum), syntans, formaldehyde, glutaraldehyde, or heavy oils. Once absorbed into the hides' collagen, the tanning agent makes these and other types of animal skins moisture-resistant and keeps them durable and flexible for many years with only minimal care.

The tanning process can be divided into three steps. Beamhouse operations consist of receiving, trimming, and soaking the skins to make them pliable and removing unwanted hair or fur and tissue. This is done by a process known as liming, where the skins are dipped in a series of pits or drums containing calcium hydroxide. Once liming is complete, the treated skins are dehaired and moved to the tanyard, where an enzyme is applied to remove residual liming chemicals and to make the skins soft and pliable and receptive to the tanning agent. Pickling, soaking the hide in a brine and sulfuric acid solution to adjust pH prior to tanning, also may be performed in the tanyard.

The tanning step can take up to three weeks as the hides are soaked in progressively stronger concentrations of either vegetable or chemical tannins, which must fully saturate the treated hide. The skins are then wrung to remove excess tannins and then cropped or split and even retanned, if a particularly heavy or thick hide is being treated. Lignosulfate, corn sugar, oils, and specialty chemicals may be added to the hide, to improve its appearance, dura-

bility, or texture. The leather then is stretched and allowed to dry or may undergo additional chemical processing such as fat liquoring, which replaces some of the natural oils lost during tanning. The finishing process can include buffing the leather to produce a suede finish; waxing; shellacking; applying pigments, dyes, and resins for smoothness; polishing for a desired color; or lacquering with urethane to make glossy patent leather. Many leathers are treated with water- or solvent-based finishes and glued or attached to another fabric or material.

As might be expected, the use of both mechanical processing operations of scraping and trimming and chemical treatment can result in the generation of large amounts of hazardous and nonhazardous residues. Typical waste products from leather treating and manufacturing operations include spent and dilute organic solvents, particularly trichloroethylene (TCE), from fat-liquoring, drying, and soaking; ammonia from wet processing during deliming and dehairing, or if ammonia is used to aid dye penetration during coloring; and chromium from use as a tannin in soaking and drying and from the buffing process. Leather-making facilities can also emit a particularly obnoxious smell, a combination of rotting flesh and sour chemicals that has traditionally relegated them to the outskirts of town.

In addition to all the other needs a manufacturing business has, such as proximity to markets and transportation centers, a steady workforce, and inexpensive, available land, a tannery requires large quantities of freshwater. Tanneries, especially high-volume or production-type operations, use water in almost every step of their operation, from cleaning hides to rinsing finished goods, and a reliable supply is essential to a smoothly functioning business. In Massachusetts, just 10 miles (16 km) north of downtown Boston, the city of Woburn seemed an ideal place for a tannery, as well as other types of industrial manufacturing activities.

Woburn (2000 population of about 37,000) is an industrial center in central Massachusetts on the Aberjona River, a six-mile- (9.7-km-) long watercourse that has been described as one of the most heavily urbanized in the Northeast. Largely channelized, the Aberjona River flows southward from Reading through Woburn and empties into the Mystic Lakes, a one-time public water supply. Close to the major markets of Boston and with plenty of freshwater available, Woburn, by the middle of the 1860s, had more than 20 tanneries and currying (leather treating) facilities, all of them using the Aberjona as a water supply and sewer. By the 1870s, water quality in the river had deteriorated to the point that the Massachusetts legislature banned the discharge of wastes into one of its



**Smokestack at the former Industri-Plex chemical plant in Woburn, Massachusetts, ca. 1996** (Jim Davis/Boston Globe/Landov)

major tributaries (Horn Pond Brook), and, by 1911, outlawed discharges of wastes into the Aberjona itself.

### POLLUTION OF THE SITE

Despite these early attempts to improve Aberjona River water quality, local businesses and the city of Woburn continued to use the river both as a water supply and for disposal of sanitary and industrial wastewater, albeit in a much more controlled manner. In the mid-1960s, in an attempt to reinvigorate its declining industrial base, the city designated a 245-acre (98-ha) tract of land on its northern side, near the intersection of Routes I-93 and I-95, as an Industri-Plex. It was a specially zoned industrial area where manufacturing and other heavy industry would be encouraged to move and expand. With a long history of prior chemical and glue manufacturing in support of the local leather industry, the Industri-Plex site was gradually redeveloped throughout the 1970s and into the early 1980s and became home to paper, textile, pesticide (lead arsenate), and expanded leather-goods industries.

As development of the Industri-Plex went forward, the city of Woburn installed two additional water supply wells. In 1964, well G was drilled, and in 1967 well H was drilled. These wells tapped groundwater present in the interconnected fractures in the bedrock beneath the Aberjona River valley and could yield up to 2 million gallons (7.6 million L) per day. Periodically tested for bacteria and other basic water quality indicators, criteria it regularly met, water from wells G and H was piped into the municipal supply system without treatment. By the late 1970s, these two wells were supplying up to 30 percent of the city's water. Then, in 1979, while on routine patrol, police officers found 200 drums of waste solvent abandoned on a vacant lot near wells G and H. To their credit, they quickly realized that the presence of these drums might have adversely affected the groundwater quality, and they notified local health officials. Water samples were taken and laboratory results indicated that well water contained elevated levels of volatile organic compounds (VOCs), most notably trichloroethylene (TCE).

Later that year, two requests for assistance were made to the federal government's Centers for Disease Control (CDC). The first was by an official of the Massachusetts Department of Public Health, who noticed an increase in mortality rates for various cancers in Woburn and was investigating whether they were related to pollution from the facilities at the Industri-Plex. The second request was from a pediatric hematologist at Massachu-

setts General Hospital in nearby Boston. This doctor advised the CDC that he had evaluated six children with acute lymphocytic leukemia from Woburn, all living within a six-block radius of each other. A local clergyman later announced to the mayor and press that he had uncovered 10 childhood leukemia cases in one part of town that had developed over the past 15 years. The CDC later concluded that death rates in Woburn between 1969 and 1978 were statistically higher by 13 percent than in similar populations.

As the health studies were being done, the city of Woburn arranged for an alternate water supply, and the Massachusetts Department of Environmental Protection and the U.S. Environmental Protection Agency (EPA) began the laborious process of determining where the contamination had originated and who was responsible for it. They focused their attention on the Industri-Plex and found that six separate properties on the site were contributing contamination to the aquifer that supplied wells G and H.

### THE CLEANUP

The Industri-Plex site and several surrounding areas were added to the National Priorities List as a Superfund site on September 8, 1983. The 330-acre (132-ha) site includes former and more recent waste disposal areas as well as adjacent wetlands and the Aberjona River. Runoff from contaminated areas flowed through wetlands and accumulated in Aberjona River bottom sediments, which are contaminated with polycyclic aromatic hydrocarbons (PAHs) and heavy metals including arsenic, chromium, and mercury. The pollution was caused by a combination of accidental discharges and intentional disposal of waste materials on the property owned or formerly owned by the responsible parties: W. R. Grace, Unifirst Corporation, New England Plastics, Olympia Nominee Trust, Beatrice Foods, and Wildwood Conservation Corporation. Although initially reluctant to assume responsibility for the cleanup, these companies entered into a negotiated settlement with EPA for \$70 million to fund cleanup activities.

These cleanup activities include removal of aboveground waste materials including drums of solvent and PCBs, "hide piles" of unprocessed or off-spec animal skins, and other debris on the site, often for decades, as well as securing the site from public access. They also include excavation and removal of more than 200 tons (180 metric tons) of soil for off-site disposal, as well as treatment of other soil in place with chemical oxidation and vapor extraction technologies. Finally, the cleanup requires dredging and restoration of ponds and wetlands that became contaminated from overland flow of surface



runoff and capping of certain impacted areas to reduce the amount of contaminated runoff entering the ecosystem.

Groundwater is being collected and treated from each of the source area properties to reduce its potential to migrate and recharge the Aberjona River aquifer system. As of 2006, more than 300 million gallons (1,134 million L) of contaminated groundwater had been withdrawn from the bedrock, treated to remove or reduce contaminant levels, and discharged into the Aberjona River. Remedial activities at this Superfund site are expected to continue for many years.

### THE AFTERMATH

In what is one of the most tragic footnotes in the history of U.S. environmental pollution, in 1982, eight Woburn families whose children had died of leukemia filed a very highly publicized lawsuit against several of the companies they considered responsible for the contamination of wells G and H. One of the main issues under dispute was whether drinking TCE at the levels found in the Woburn well water could have resulted in childhood leukemia. Although there was some evidence of a connection, there was no broad scientific consensus that such a link could be made authoritatively. After protracted litigation, including a jury trial, they were awarded a modest financial settlement, one that could never replace or make up for the suffering and loss of their children. It was this case that was described in *A Civil Action*.

See also AQUIFER; ARSENIC; CHROMIUM; EX SITU REMEDIATION OF CONTAMINATED GROUNDWATER; IN SITU GROUNDWATER REMEDIATION; LEAD; MERCURY; PAH; PESTICIDES; SUPERFUND SITES; TCE; VOLATILE ORGANIC COMPOUND; WELL.

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### World Trade Center Disaster New York, New York (September 11, 2001) Air Pollution

On the morning of September 11, 2001, two jetliners hijacked by terrorists were purposefully crashed into the North and South Towers of the World Trade Center within one hour of each other in Lower Manhattan, New York City. More than 2,800 people were killed directly by the attack, and victims were still being found and identified by deoxyribonucleic acid (DNA) through 2007. The Twin Towers, which had been the symbols of American trade and commerce, collapsed in a twisted mass of steel and other debris into a hole that would take more than a decade to fill. The horror, death, and destruction of the event captivated people's attention to the exclusion of any other problems. These attacks led directly to military action in Afghanistan and Iraq and a new heightened awareness and even fear of terrorism among Americans.

Behind these blazing headlines, however, the fire and collapse of each tower generated a dangerous mixture of toxic smoke and gas that enveloped hundreds of buildings and potentially affected the health of thousands of residents, emergency response personnel, and construction workers. It is estimated that 250,000–400,000 people were immediately exposed to a mixture of dust, debris, smoke, and various chemicals. The effects of exposure to the environmental fallout of the disaster will be felt for many years in the health of the numerous victims of the tragedy.

### BACKGROUND

The idea to build the world's tallest buildings on the 16-acre (6.5-ha) parcel within Vesey, Liberty, Church, and West Streets was originally planned

in the early 1960s to revitalize the area by David Rockefeller, chairman of Chase Manhattan Bank, and his brother, Governor Nelson Rockefeller. Built and operated by the Port Authority of New York and New Jersey, its construction began in 1966.

Five city blocks were closed and more than 160 buildings demolished to make room for the two 13.4-million-square-foot (1.27-million-m<sup>2</sup>), 110-story high buildings, which included a central landscaped plaza and a retail shopping mall, the largest in Lower Manhattan, with six basement levels and three subway stations. Some 3,500 workers toiled for six years to remove 1.2 million cubic yards (1 million m<sup>3</sup>) of soil and build one of the most recognizable symbols of New York and American capitalism. By 1972, both towers were open for occupancy. In 2001, 50,000 people worked in the buildings on a daily basis with tens of thousands of others either visiting or passing through the mall on the way to nearby buildings, including the Mayor's Office, New York Stock Exchange, and Federal Plaza. All of the original buildings in the complex were destroyed as a result of the 2001 terrorist attacks.

The destroyed buildings included One World Trade Center (the North Tower), Two World Trade Center (the South Tower including the observation deck), and Seven World Trade Center (a 47-story office building), all of which collapsed. Three World Trade Center, the Marriott Hotel, was crushed by the collapses of the North and South Towers. Four and Five World Trade Center (two nine-story low-rise office buildings) and Six World Trade Center (the U.S. Customs House, a seven-story low-rise building) were damaged beyond repair and later were demolished. More than 2,800 people died at the World Trade Center site, including 343 firefighters and 66 police officers, as well as the 148 passengers and crew on the hijacked planes, along with the hijackers.

The overwhelming number of responders to the disaster site included personnel from many federal, state, and local agencies, as well as from private organizations, and various other workers and volunteers. The agencies and organizations include the Agency for Toxic Substances and Disease Registry (ATSDR), the Centers for Disease Control and Prevention (CDC), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the Federal Bureau of Investigation (FBI), the Federal Emergency Management Agency (FEMA), the National Institute of Environmental Health Sciences (NIEHS), the National Institute for Occupational Safety and Health (NIOSH), the National Park Service, the Occupational Safety and Health Administration (OSHA), the Public Health Service

Commissioned Corps, the Substance Abuse and Mental Health Services Administration (SAMHSA), the U.S. Coast Guard, the U.S. Marshals Service, the New York State Department of Environmental Conservation, the New York State Emergency Management Office, the New York State National Guard, the New York State Office of Mental Health, the New York State Department of Health, the New York City Fire Department (FDNY) and emergency medical services (EMS), the New York City Department of Health and Mental Hygiene, the New York Police Department (NYPD), the New York City Department of Design and Construction, the New York City Department of Environmental Protection, the New York City Department of Sanitation, the New York City Office of Emergency Management, the American Red Cross, and the Salvation Army. All these people who responded to the site were exposed to the contaminants unleashed in the disaster.

### POLLUTION OF THE AREA

As the North and South Towers collapsed, a plume of smoke and dust cascaded through the streets of Lower Manhattan and rose more than 1,000 feet (305 m) into the air. Survivors fleeing for their lives and emergency response personnel rushing to their aid were exposed to a pulverized mixture of plastics, metals, hydrocarbons, cement, and numerous other toxic materials.

One inventory of the debris pile, which reached six stories in height and took up several city blocks (commonly called Ground Zero), included 200,000 tons (181,437 metric tons) of steel, 1,000,000 tons (907,185 metric tons) of concrete, 600,000 square feet (55,742 m<sup>2</sup>) of glass, and untold amounts of paper, computers, desks, filing cabinets, cleaning supplies, electric cables, air conditioners, and the wreckage of the hijacked airplanes. Residues from these materials remained suspended, settled out, and were resuspended over the next four days by wind, emergency vehicles, and recovery efforts, until a soaking rain on September 16 finally stabilized the dust. It took until December 20, when the fires burning in the rubble were finally extinguished, for smoke and related combustion products to begin to dissipate.

Hundreds to thousands of chemical compounds were entrained in the dust and smoke from the collapse of these buildings and the associated debris fires. Most public health and epidemiological studies, however, have focused on five key materials as having the potentially greatest impacts on public health:



**Debris from World Trade Center awaiting forensic processing at Fresh Kills landfill on Staten Island, New York, City, January 2002** (Mike Segar/Reuters/Landov)

### Asbestos

Asbestos is a group of fibrous, naturally occurring minerals. It is an extremely useful industrial mineral because of its relative abundance, which makes it fairly inexpensive, and its fibrous nature, which allows it to be added or woven easily into a variety of products. Asbestos's strong resistance to heat and fire, as well as its general nonreactive nature, makes it ideal for use in high-temperature applications such as brake linings, gaskets, and ovens. One of the most common applications for asbestos was as a flame and fire retardant, which was its main application in the World Trade Center. Asbestos is commonly mixed into cement or sprayed as quick-setting slurry directly onto steel beams or structural supports. If the steel is bent, the coating flakes off and can be pulverized, as can the cement.

Exposure to airborne asbestos was the main public health concern after the 9/11 attacks. Asbestos was extensively used as a fireproofing agent in the construction of the World Trade Center buildings, and, although some had been removed over the 30-year life span of the complex, hundreds of tons remained in its concrete and on the coatings of steel support beams.

More than 12,000 samples of dust and debris were sampled and analyzed for asbestos by the EPA. Most of the data consistently indicated that outside air

measurements of asbestos were below public health standards and typical for urban air. The notable exceptions included analysis of samples that were collected close to and just after the attacks in defined "restricted areas" at Ground Zero and samples from within nearby apartments, where dust was able to settle and accumulate. The Fresh Kills landfill on Staten Island, where the debris was disposed of, also had asbestos levels above acceptable levels in some cases.

The inhalation of asbestos fibers has long been associated with health problems in asbestos miners and handlers. In 1989, the EPA banned most uses of asbestos because of concerns related to more widespread or general public health exposures. Health effects related to inhalation of asbestos include asbestosis, or scarring of the lungs caused by an acid produced when the body tries to dissolve the invading fibers; mesothelioma, a type of cancer of the lungs, abdominal cavity, or pericardium (the sac surrounding the heart); and other types of cancer including gastrointestinal, kidney, and liver. Long latency periods, often on the order of 10–30 years, are associated with the development of asbestos-related disease.

### Particulate Matter

Particulate matter (PM), also called aerosols (liquid) or smoke (solid), are small particles of material sus-



pendent in a gas. Once inhaled, the particle's diameter controls how it will be distributed within the body. Particulate matter larger than 10 micrometers ( $PM_{10}$ ) is usually filtered by nasal hairs or mucus membranes in the throat. It was these larger particles that were responsible for a condition among construction workers and response personnel known as WTC cough. These large dust particles were mostly pulverized fragments of alkaline and caustic concrete and fiberglass, which irritated throats and nasal passages.

Particles between 10 and 2.5 micrometers are most often trapped in the upper airways of the lung and do not represent much of a health risk to healthy people depending upon their composition. Particles with extreme pH, either acidic or basic, can cause scarring of the bronchial tubes, and conditions such as chronic bronchitis can result. Much of the dust at the World Trade Center site was pulverized sheet-rock, which is primarily gypsum, a sulfate mineral. It can be reacted to form sulfurous and sulfuric acid in the body. Other particles were composed of multiple compounds, some of which were organic compounds that resulted from burning jet fuel and plastic items such as polycyclic aromatic hydrocarbons (PAHs), which are known human carcinogens. At-risk people, including asthmatics, the very young and very old, and people with chronic obstructive pulmonary disease (COPD), may also suffer severe to even fatal reactions to exposure to this size of particulate.

Particles smaller than 2.5 micrometers ( $PM_{2.5}$ ) can penetrate deeply into the lungs, bronchi, and alveoli. They can be absorbed directly into the bloodstream with the gases necessary for life. Commonly in aerosol form, they can include numerous organic compounds that can be harmful or carcinogenic such as PAHs. These small particles have been linked to increased incidences of asthma, lung cancer, and other respiratory diseases, even premature death.

Those present at Ground Zero within four to eight hours after the collapse of the North and South Towers were exposed to very high levels of PM. By mid-October, however, PM levels in Lower Manhattan returned to levels typical of those for other areas of New York City.  $PM_{2.5}$  levels decreased rapidly with distance from Ground Zero and generally within three to 10 blocks from the WTC site, they were at or below ambient air quality values. The EPA concluded that PM may have resulted in an increased risk of chronic health problems for those most heavily exposed.  $PM_{2.5}$  concentrations, however, do not seem to pose a significant risk to those who remained farther away from the disaster site.

## Metals

Lead, chromium, and nickel were present in building materials and furnishings such as paint, cables, plumbing fixtures, desks, and chairs throughout the North and South Towers. Analysis of protected dust samples up to six inches (15.2 cm) thick from window ledges and building roofs indicated that individuals exposed to dust shortly after the collapse probably inhaled lead and chromium in excess of regulatory levels. The concentration of these metals, however, decreased rapidly within a few blocks of Ground Zero, and no nickel was detected at concentrations above background levels at any location. Although short-term exposures to the levels estimated from dust analysis were not likely to pose increased health risks to the general public, the effects of longer-term, lower-level exposures on unprotected emergency response personnel, construction workers, or nearby residents are not known.

Exposure to other heavy metals such as mercury, cadmium, arsenic, and zinc is not known but expected to be low.

## Dioxins

Dioxin is the common name for a class of more than 200 organic compounds made up of two benzene molecules connected to either a single or a double oxygen bridge. Chlorine atoms are attached to this very large molecule at one of eight locations. Dioxins are produced when organic material such as wood or paper is burned in the presence of chlorine, which can be present in plastics and cleaning agents. Classified as a known human carcinogen, dioxin can result in a disfiguring form of chloracne with exposure to large amounts.

Between September 23 and the end of November, as the fires continued to burn and smolder in the Ground Zero rubble, airborne dioxin levels increased to between 10 and 150 picograms per cubic meter, more than 1,000 times higher than those found in typical urban areas. Those most exposed to these elevated concentrations were construction and emergency response personnel working on the ground and breathing in the heavy, low-lying smoke. Somewhat surprisingly, the EPA concluded that despite these elevated concentrations, overall health risks associated with exposure to dioxin at Ground Zero were not significant. This is because the amount of dioxin taken into the body through inhalation is very small when compared with that taken in through its primary pathway, ingestion of foods containing dioxin. Additional, follow-up studies of the exposed individuals are ongoing.



### PCBs

Polychlorinated biphenyls (PCBs) are a class of organic compounds in which chlorine atoms are connected to a special type of hydrogen and carbon molecule. PCBs have been used in such varied applications as insulating fluids in electrical equipment, as heat transfer fluids, as hydraulic fluids, and in lubricating and cutting oils. They have also been used as additives in paint and pesticides. They are chemically stable and have a high flash point. This physical and chemical stability has contributed to their persistence in the environment and ultimate bioaccumulation in animals and people. By the late 1970s, the use of PCBs had declined greatly because of environmental concerns and increasing regulatory pressures, except for very specialized applications, such as in electrical capacitors and transformers. Health effects associated with exposure to high concentrations of PCBs are skin rashes and chloracne. Both the EPA and the IARC (International Agency for Research on Cancer), however, have classified PCBs as probable human carcinogens.

At the World Trade Center site, low levels of PCBs were found in smoke from fires that were burning building materials containing PCBs. The highest recorded concentration was 153 nanograms per cubic meter. Typical urban air contains PCBs in the range of 1–8 nanograms per cubic meter, and the permissible exposure level for American workers (Occupational Safety and Health Administration [OSHA] regulations) for PCBs is 1 milligram per cubic meter. By the middle of October 2001, all PCB samples had values consistent with typical urban air. The EPA concluded that there were no increased cancer or noncancer risks associated with this level of PCB exposure. Possible synergistic effects of exposure to low levels of PCBs, metals, and other World Trade Center–related airborne pollutants have not been quantified. It was not until January or February 2002 that ambient air quality in the vicinity of Ground Zero returned to precollapse levels.

### HEALTH EFFECTS ON WORKERS

Within 48 hours of the attack, the New York City Fire Department found that about 90 percent of its 10,116 firefighters and EMS workers evaluated at the WTC site reported an acute cough and gastrointestinal problems. Many slowly recovered from these effects, but others did not, and still others died of the effects. Some 46 percent of the responders continue to experience at least one pulmonary symptom and 52 percent still experienced ear, nose, and throat symptoms nine months after the attack. As of March

2004, 380 firefighters were no longer able to serve as firefighters as a consequence of respiratory illnesses they developed after WTC exposure. The risk of chronic respiratory problems such as reactive airway dysfunction syndrome, irritant-induced asthma, and WTC cough appears to be associated with intensity of the exposure, defined as the time of arrival at the site and duration of exposure. Residents of the area also experienced adverse health effects from more remote exposure. A study conducted between October 25 and November 2, 2001, showed that about 66 percent of nearby residents most frequently reported symptoms of nose or throat irritation, and about 47 percent reported a persistent cough.

### THE CONTROVERSY

Immediately after the disaster, the director of the EPA, Christine Whitman, released a statement reassuring the residents and workers that there was no apparent health threat from the dust and gases in the area. Mayor Rudy Giuliani made similar comments but with a bit less certainty. After it became clear that there was a significant health threat, something of a cover-up unfolded. The original findings by the EPA were downplayed by President George W. Bush's White House staff in an effort to prevent panic. The Whitman statement had been edited by the White House. Later, Whitman defended herself that the EPA did not have the authority to require rescue and relief workers to wear protective clothing and that it was the responsibility of New York City to monitor these details. The controversy escalated over the years after the disaster to the point of congressional investigations and final admission of the poor handling of the environmental and public health aspects.

Senators and representatives from the area successfully lobbied for allocation of \$12 million in December 2001 to establish the World Trade Center Worker and Volunteer Medical Screening Program run by Mount Sinai Hospital. This was the first program to track and monitor the health of 9/11 responders. The group later was able to secure an additional \$90 million to expand the number of workers and volunteers eligible. They also successfully lobbied Congress to restore \$125 million in additional funding for long-term medical and mental health monitoring and treatment. There are several agencies that are involved in this program. The Agency for Toxic Substances and Disease Registry (ATSDR) entered into a cooperative agreement with the New York City Department of Health and Mental Hygiene in 2003 to continue support of the

WTC Health Registry for five years of its planned 20-year duration. The National Institute of Occupational Safety and Health (NIOSH) awarded five-year grants in July 2004 to continue the FDNY and Mount Sinai programs, which had begun in 2001 and 2002. In 2010, the U.S. House of Representatives failed to pass a bill that would have provided extended health care coverage to thousands of September 11 first responders. The James Zadroga 9/11 Health and Compensation Act, named for a New York City detective who died of a respiratory disease attributed to exposure to pollutants from the disaster, could not garner the support for passage.

See also AIR POLLUTION; ASBESTOS; CHROMIUM; DIOXIN; LEAD; PAH; PARTICULATE; PCBs.

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# X

**xylene** Xylene is one of the most widespread and widely applied chemicals in the United States. It is typically among the top 30 chemicals produced in terms of volume. As one of the BTEX (benzene, toluene, ethylbenzene, xylene) components of gasoline, it is used on a daily basis throughout the world. As such, it is consequently one of the most widely distributed organic contaminants. Xylene, which is also known as dimethyl benzene, Xylol, methyltoluene, and Violet 3, has both artificial and natural sources and is released as both point source and nonpoint source pollution. It is dangerous enough to human health to be regulated and monitored. Considering that it occurs in 844 of the first 1,662 U.S. Environmental Protection Agency (EPA)–designated Superfund sites on the National Priorities List, its monitoring and regulation are no easy tasks. This is among the highest percentage for any of the hazardous chemical pollutants. As a result of the widespread distribution and adverse health effects associated with it, xylene has been ranked the 58th most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

## PROPERTIES, USES, AND PRODUCTION

Xylene is an organic compound that is typically a mixture of three methyl group isomers, meta-xylene, ortho-xylene, and paraxylene, and may be referred to as mixed xylenes or total xylenes. Though their components may vary, mixed xylenes are commonly 40 percent m-xylene and 20 percent each of o- and p-xylene, with toluene and other compounds forming the remaining 20 percent. Xylene is typically a colorless, highly flammable liquid with a sweet odor that occurs naturally in crude oil and coal tar. It can also

be produced in small quantities from some plants and from forest fires or the burning of tobacco. The primary use of xylene is as a solvent and a substitute for benzene, which is less safe. It is primarily used in the printing industry, in rubber making, and for leather products, typically with benzene and toluene. It is used to synthesize many liquid chemicals including phthalic acid and isophthalic acid, among others, and solids such as plasticizers (phthalates), polyester film, fabric and paper coatings, and some fabricated items. As a solvent, xylene is used in paint thinner, paint remover, resin, varnish, paint, shellac, enamels, lacquers, rust preventative, rubber cement, agricultural pesticides, and industrial and residential cleaners and degreasers. It is also used to make additives for fuels. The industrial production of xylene was approximately 5 billion pounds (2.3 billion kg) in 1982 and increased to 6.84 billion pounds (3.1 billion kg) by 1993.

## ENVIRONMENTAL RELEASE AND FATE

Release of xylene into the natural environment results primarily from emissions from petroleum refining and the exhaust of gasoline and diesel engines and residential and commercial oil furnaces. These sources can be both point source and nonpoint source pollutants. Other releases are from industrial emissions, spills and dumping, and leaks and evaporation from fuel transport and storage as well as pesticide spraying. During the EPA Toxic Release Inventory program of 1987–93, approximately 4.8 million pounds (2.2 million kg) of xylene was reportedly released to the natural environment. Of this release, about 81 percent was to land and primarily from the petroleum refining industry. About half of

the total release during this time was in Texas, with far lesser amounts in New Jersey, Illinois, Indiana, Alabama, California, Michigan, Georgia, Virginia, and Washington, in decreasing order of release. In 2006, total reported industrial mixed xylenes release was 31,955,403 pounds (14,525,183 kg), making xylene one of the most widely released pollutants.

Xylene is a volatile organic compound (VOC) and, as such, evaporates readily. By far, the most common pathway of release is into the air, where the xylene quickly degrades through photochemical reactions with hydroxyl radicals with a removal half-life of one to 18 hours depending upon conditions. Xylene evaporates quickly from surface waters with a removal half-life for rivers and streams of about 3.2–29 hours depending on conditions. In ponds, it is a bit slower with a half-life of about 144 hours depending upon conditions. Otherwise, xylenes are relatively resistant to chemical reactions and do not biodegrade quickly. Xylene released to soil is relatively mobile and adheres to clay and organic material poorly, if at all. It evaporates quickly from the surface of the soil, but once it enters the subsurface, evaporation is slow and it may quickly leach into the groundwater system. Leaching is very quick in sandy soils and somewhat slower in clay and organic-rich soils. Some biodegradation takes place in soil and groundwater, but field tests have shown that it may persist from months to years.

### HEALTH EFFECTS FROM XYLENE EXPOSURE

Virtually everyone is exposed to xylene through everything from automotive exhausts to cleaners and solvents to cigarette smoke to industrial emissions. There are a number of adverse health effects that may result from this exposure. Acute exposure to xylene produces a variety of symptoms such as eye, nose, and throat irritation; and headache, dizziness, difficulty in breathing, respiratory failure, and pulmonary congestion, followed by death if the dose is high enough. Long-term chronic exposure has been shown to produce central nervous system effects such as confusion, loss of balance, memory loss, headaches and migraine headaches, and malaise. Other effects include abdominal discomfort, chest pain, fever, numbness in the hands, impaired lung function, electrocardiograph abnormalities, pulmonary edema, and liver and kidney damage. Animals exposed to xylene at acute levels have experienced muscular spasms, hearing loss, loss of coordination, and changes in behavior, as well as death if the dose is high enough. Long-term effects include damage to the central nervous system, liver, kidneys, blood system, lungs, and heart, as well as increased mortality

rate. Rats showed bone marrow and spleen damage. When pregnant animals were exposed to xylene, there was a greater incidence of low birth weight, birth defects, and delayed skeletal development, as well as developmental problems after birth such as poor motor coordination and spatial navigation. Xylene is not classified as a carcinogen (EPA group D) and does not appear to be, but, surprisingly, the full cadre of appropriate studies to render an evaluation have apparently not been performed.

### REGULATION OF HUMAN EXPOSURE

As a result of the adverse health effects and widespread distribution of xylene, federal agencies regulate human exposure. The EPA has set a drinking water limit of 10 parts per million (ppm) of xylene under the Safe Drinking Water Act. They further recommend that children not ingest water with levels of 40 ppm or more for periods greater than 10 days. Every spill of mixed xylenes or p-xylene of 100 pounds (45 kg) or more and every spill of m- and o-xylenes of 1,000 pounds (454 kg) or more must be reported to the National Response Center. The Occupational Safety and Health Administration (OSHA) set an exposure limit of 100 ppm in work area air for an eight-hour-day, 40-hour workweek. For peak exposure, the limit is 150 ppm for 15 minutes. The National Institute of Occupational Safety and Health (NIOSH) recommends the same exposure limit as OSHA as well as a short-term exposure limit (STEL) of 200 ppm for 10 minutes and an immediately dangerous to life and health (IDLH) exposure level of 900 ppm. According to the NIOSH National Occupational Exposure Survey (1981–83), some 2,145,039 American workers were exposed to xylene in the workplace.

*See also* BENZENE; ETHYLBENZENE; ORGANIC POLLUTANTS; PHTHALATE; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES; TOBACCO SMOKE; TOLUENE.

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# Y

## **Yucca Mountain Waste Repository Nye County, Nevada (ca. 2017– )** *Waste Pollution*

Probably the most studied piece of ground on planet Earth is a five-mile- (8-km-) long, 25-feet- (7.6-m-) wide, U-shaped tunnel carved into a ridgeline of volcanic rock in Nye County, Nevada, about 100 miles (161 km) northwest of Las Vegas. Yucca Mountain, or more appropriately, the Yucca Mountain Project, has been selected to be the final waste repository for all of the unusable nuclear fuel and discarded high-level radioactive waste produced in the United States. Approximately 90 percent of this waste will be spent nuclear fuel from commercial power plants, government research reactors, and U.S. Navy submarines and ships. These rods are made up of specially enriched plutonium and uranium that has decayed to the point where it no longer efficiently produces

enough heat to generate the pressurized steam that turns the electrical generating turbines in a nuclear power plant. The other 10 percent is high-level radioactive waste generated from the reprocessing of spent nuclear fuel. Both of these waste types are made up of radioactive elements such as strontium, technetium, and neptunium that have decay half-lives ranging from only a few years to millions of years. The proper disposal of these wastes, which are now stored at almost 80 sites scattered across 35 states, has become essential for reasons of both national security and long-term energy policy. If electricity from nuclear power plants is to play a role in meeting the growing demand for energy in the United States, and in reducing greenhouse gas (CO<sub>2</sub>) emissions, then a safe, secure repository for its waste products must be established.



**Tunnel boring machine entering access portal at Yucca Mountain, Nevada Test Site, Mercury, Nevada, 1994**  
(DOE Photo)

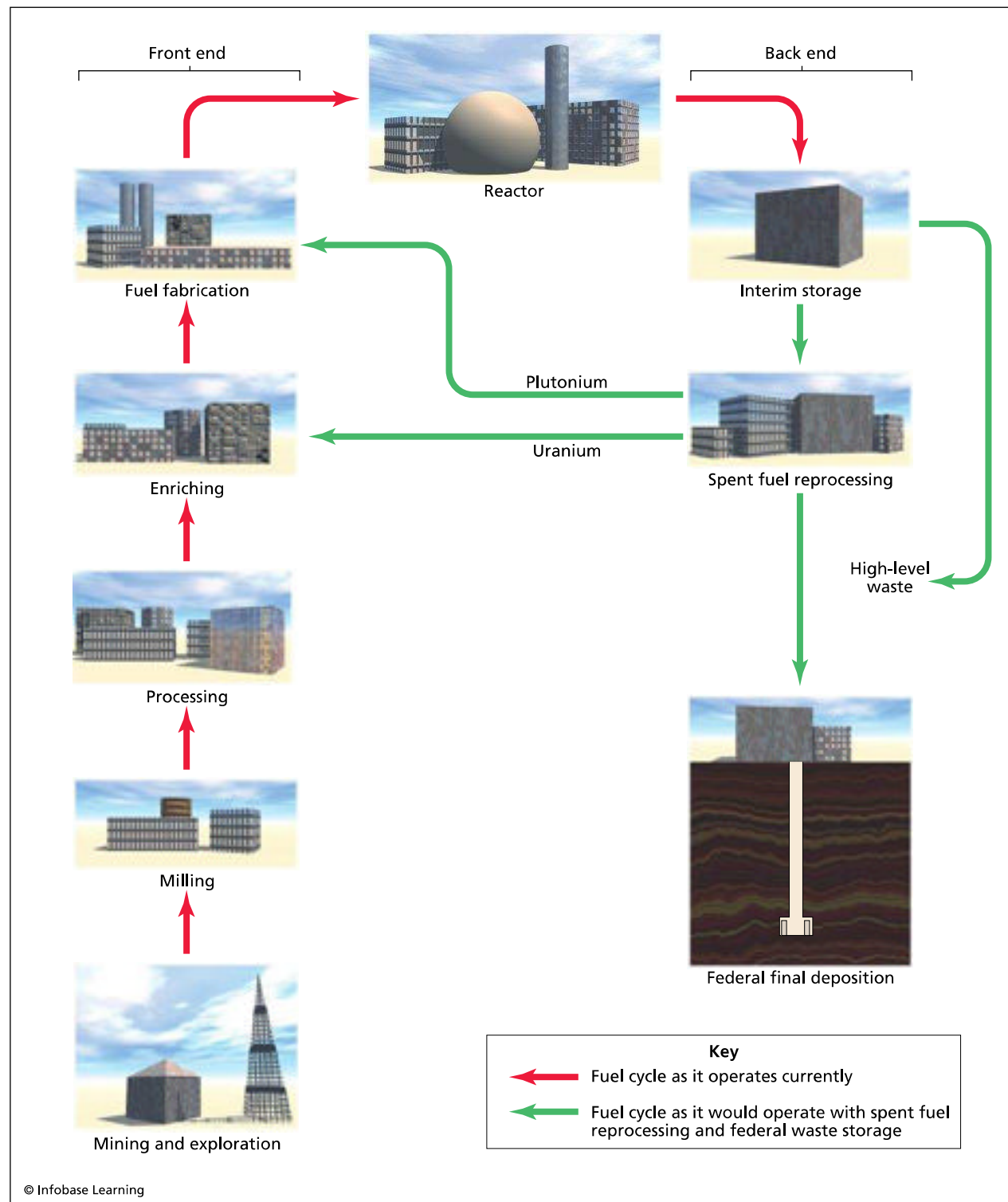
## **SITE CHARACTERISTICS**

Yucca Mountain is composed largely of Miocene age (5–20 million years old) silica-bearing volcanic ash flow and ash fall deposits that have been consolidated and hardened over time into the volcanic rock tuff. The ash that forms the tuff was produced by a series of extensive, and explosive, volcanic eruptions. The rock layer, or “disposal horizon,” where the waste will be placed, the Topopah Springs welded tuff, has physical, chemical, and thermal characteristics that make it a suitable host formation. Given the favorable host rock characteristics, many scientific and engineering studies have focused on water as the most likely way that wastes or waste by-products could escape the repository.

Yucca Mountain is in the southern part of the Great Basin physiographic province, an area that receives

only about six inches (15 cm) of rainfall or less per year. Most of this precipitation quickly evaporates or is absorbed by the area's sparse vegetative cover. The types of infiltration, or "bathtub" effects, where water ponds around the waste, that are common at so many

other disposal sites in more humid climatic zones are very unlikely to occur at Yucca Mountain. In addition, the heat being generated as part of the radioactive decay process will probably quickly evaporate water that does reach the disposal horizon.



Schematic diagram for obtaining, processing, utilizing, recycling, and disposing of nuclear fuel

The regional groundwater table is almost 1,000 feet (305 m) below the disposal horizon, and modeling studies have found that by the time waste or waste by-products are able to move through this thick, dry buffer zone, the radioactive substances would have decayed to greatly reduced levels. The groundwater that is present underneath Yucca Mountain moves very slowly and discharges onto the surface 30–45 miles (50–70 km) to the south of the site and possibly as far away as south-central Death Valley in California. These long travel times allow radioactive decay to reduce the toxicity of materials that may leak from Yucca Mountain and help reduce the risk of exposure. The tuff also contains zeolite, a hydrated, aluminosilicate mineral with a microporous structure that can hold a wide variety of cations. Commonly used as ion-exchange media in commercial water softeners, zeolites attract and retain many types of radioactive ions within their crystal lattice. This property can greatly slow the movement of radioactive ions through the groundwater.

Nevada ranks third in the nation in current seismic activity, and, since 1976, there have been more than 600 seismic events with a magnitude greater than 2.5 within a 50-mile (81-km) radius of Yucca Mountain. The mountain itself was largely formed as a result of earthquake-induced faulting and strong ground motion events that occurred over several million years. Site developers concluded that seismic and related tectonic effects on the natural systems at Yucca Mountain are occurring very slowly. Yucca Mountain has remained geologically stable for at least the last several million years. Faulting and seismic activity should not significantly affect repository performance, especially given the engineered barrier systems that have been implemented at the facility.

### THE CHOICE OF YUCCA MOUNTAIN

The ultimate choice of Yucca Mountain by the Department of Energy (DOE) as the repository was far from certain. In 1981, on the basis of information from the National Academy of Sciences and other well-respected scientific bodies, the U.S. Congress mandated that the U.S. Department of Energy (DOE) identify a geologic or underground repository for the disposal of the nation's high-level radioactive waste. By 1983, nine potential sites in six states had been identified: two salt beds in Texas; two salt beds in Utah; three salt domes, two in Mississippi and one in Louisiana; one site in the basalt of Washington State; and the welded tuff (ignimbrite) of Yucca Mountain in Nevada. After some additional

screening, the DOE recommended the Deaf Smith County Texas salt bed and Yucca Mountain for full characterization. On February 12, 2002, after almost 10 years of study, the DOE announced that Yucca Mountain was the most appropriate place to dispose of these dangerous wastes permanently. As might be expected, the governor of Nevada did not agree and appealed to Congress to void the DOE's decision. Neither Congress nor President George W. Bush would do so.

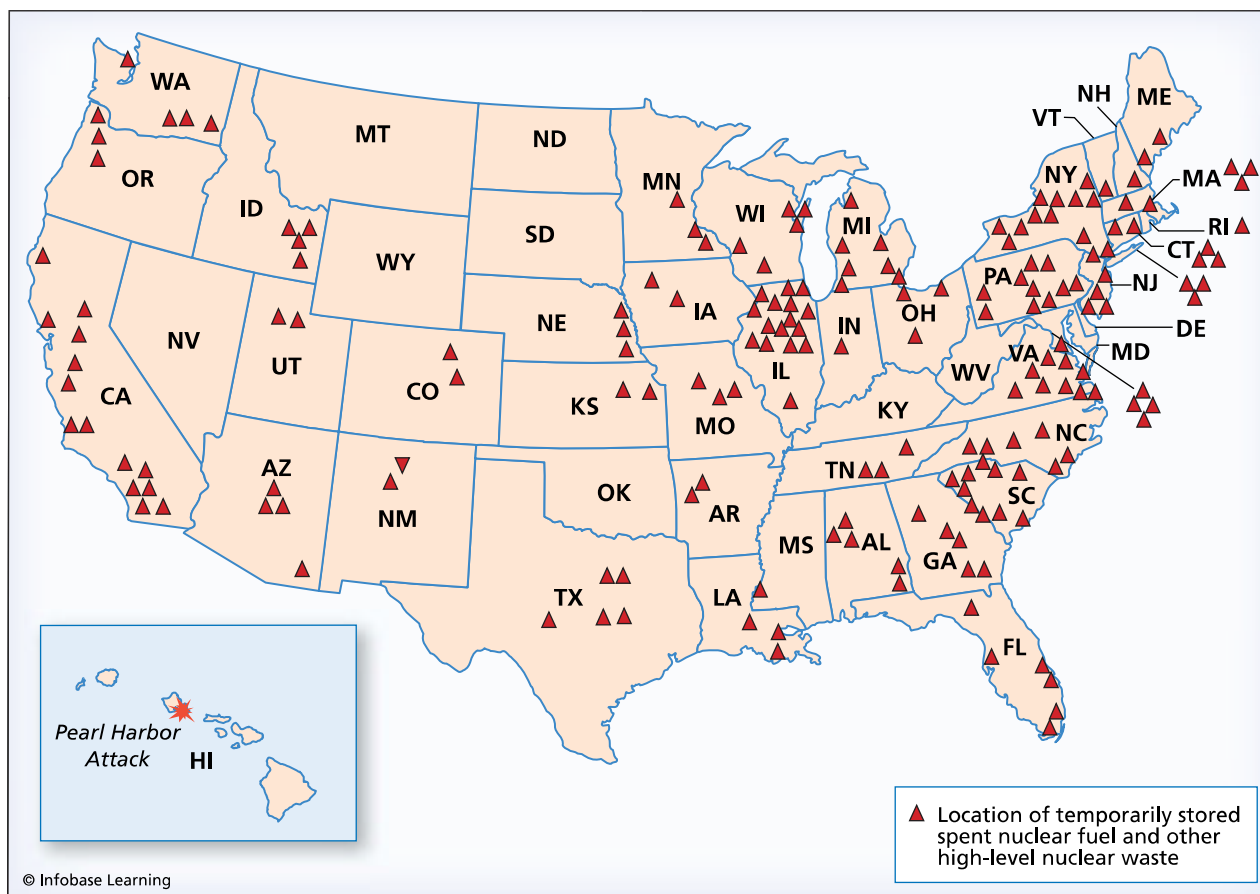
Besides its geologic and climatological setting, Yucca Mountain had a number of other attractive features. It is adjacent to the Nevada Test Site, 1,350 square miles (3,497 km<sup>2</sup>) of U.S. government-owned land used since the late 1940s for the above- and belowground detonation of almost 1,000 nuclear devices. Ellis Air Force Base is close by, along with the notorious "Area 51" of UFO fame. The DOE also counted on public support, as Nevada is more dependent on nuclear energy than many other states, with about 15 percent of Las Vegas's electricity supplied by the Palo Verde nuclear plant. Finally, when Yucca Mountain was nominated as a finalist site in the early 1980s, Nevada had only two congressmen. According to numerous newspaper and public research polls, the majority of Nevadans oppose the development of Yucca Mountain as a geologic repository for nuclear waste.

### PRODUCTION OF THE REPOSITORY

A consortium of government contractors is developing Yucca Mountain, and approximately 1,300 people work on the project. Projecting off the main U-shaped tunnel are large open rooms or vaults, where the majority of the research and testing is performed. Smaller side tunnels to be dug at right angles to the main tunnel will be used for waste disposal. The final repository will be 1,000 feet (305 m) below the ground and cover almost 1,200 acres (486 ha). The disposal horizon also will be 1,000 feet (305 m) above the top of the water table. Multilayer stainless steel and nickel alloy packages will be used to hold the waste, and these will be surrounded by titanium drip and rock shields.

Belowground workings at Yucca Mountain will consist of two inclined access ramps, vertical ventilation shafts, and flat-lying waste emplacement drifts. These drifts will be divided into two sets of waste disposal areas called blocks. The upper block, approximately 800 acres (324 ha), will be able to hold about 11,000 waste packages. The lower block, about 170 acres (69 ha), will accommodate up to 2,400 waste packages. Overall, those facilities cur-





**Map of the United States showing the locations of temporary waste repositories for spent nuclear fuel and other high-level nuclear waste in 1994. They await transport to a permanent site, such as Yucca Mountain in Nevada.**

rently storing high-level wastes around the United States including nuclear power plants, research facilities, and military operations are expected to ship 12,000 specially designed waste packages to Yucca Mountain for disposal.

Finally, the last defense against water is the containers into which the waste materials will be placed for disposal. Each is constructed of two layers, first, a four-inch- (100-mm-) thick outer barrier designed to withstand conditions that will be present after the initial placement of the container in the disposal block, namely, humid air at elevated temperatures. This outer barrier will be made up of a mixture of nickel, chromium, molybdenum, iron, tungsten, and cobalt. Over time, conditions inside the repository may become cooler and wetter and a second, 0.8-inch- (20-mm-) thick corrosion barrier also will be installed inside each disposal container to provide additional protection from those conditions. This layer, a titanium alloy, forms a passive oxide film over its surface that is stable over a wide range of temperature, pH, and moisture conditions. Disposal container lids for both inner and outer layers will

be welded on by using remote procedures that will take up to 33 hours per container. These containers have been designed to remain intact for thousands of years but do not shield or prevent the escape of radioactivity. That is the purpose of the geologic repository.

The total cost of site development is expected to be in the range of \$100 billion, with most of this paid for as a surcharge on electricity produced by nuclear power plants. Of course, this surcharge is passed along to the public in monthly utility bills. The federal government also is paying part of the cost, with money being allocated from taxpayer-funded U.S. Department of Defense (DOD) and DOE budgets. Yucca Mountain is anticipated to begin accepting waste for permanent disposal on March 31, 2017.

### A COLLABORATIVE PROJECT

The DOE is responsible for the siting, development, and operation of Yucca Mountain, but a number of other government agencies have been mandated to

make sure the design and long-term performance are protective of the public health and environment. The U.S. Geologic Survey provides technical support in characterization and design studies. The Nuclear Regulatory Commission (NRC) is responsible for determining whether DOE will receive the necessary licenses to dispose of spent nuclear fuel and high-level radioactive waste in the repository. If the Yucca Mountain site is approved to accept waste, shipments by NRC licensees to the site will have to be made in accordance with NRC and Department of Transportation (DOT) regulations. The U.S. Environmental Protection Agency (EPA) has a major role in the development of safety standards for the site. The EPA's standards address all air, groundwater, and soil environmental pathways and have been developed to be protective of public health for the next million years. The EPA has proposed two dose standards. For the first 10,000 years, a dose limit of 15 millirem per year to the general public living in the area of Yucca Mountain is required. This is the most stringent radiation standard in the United States. Between 10,000 and 1 million years, the EPA requires that the facility not expose the public to a dose greater than 350 millirem per year, which is no higher than natural or background radiation levels for this area of the country.

### THE CONTROVERSY

With so much at risk, opponents of this solution to the high-level waste disposal problem regularly challenge the use of Yucca Mountain as a repository. They maintain that the remote nature of the site is being threatened by the explosive growth in and around the city of Las Vegas, only 100 miles (161 km) to the southeast. Population pressures will increase, and risks related to inadvertent human intrusion will become greater over time, especially over the tens of thousands of years when the waste will remain radioactive.

The large-scale volcanic eruptions that produced Yucca Mountain ended about 12 million years ago, and, about 3 million years ago, a series of smaller, less explosive eruptions and lava flows took place in the area. The last such small eruption occurred about 80,000 years ago. Opponents maintain that these types of geologic events are difficult to predict and, if one occurs, it could result in catastrophic failure of the repository.

The rocks at Yucca Mountain are cracked and broken in places. In some cases, these cracks may extend from the planned storage area to the underlying water table. Some hydrologists think that the joints provide a way for radioactive waste to escape the repository after the waste containers fail several tens of thousands of years from now. In addition,

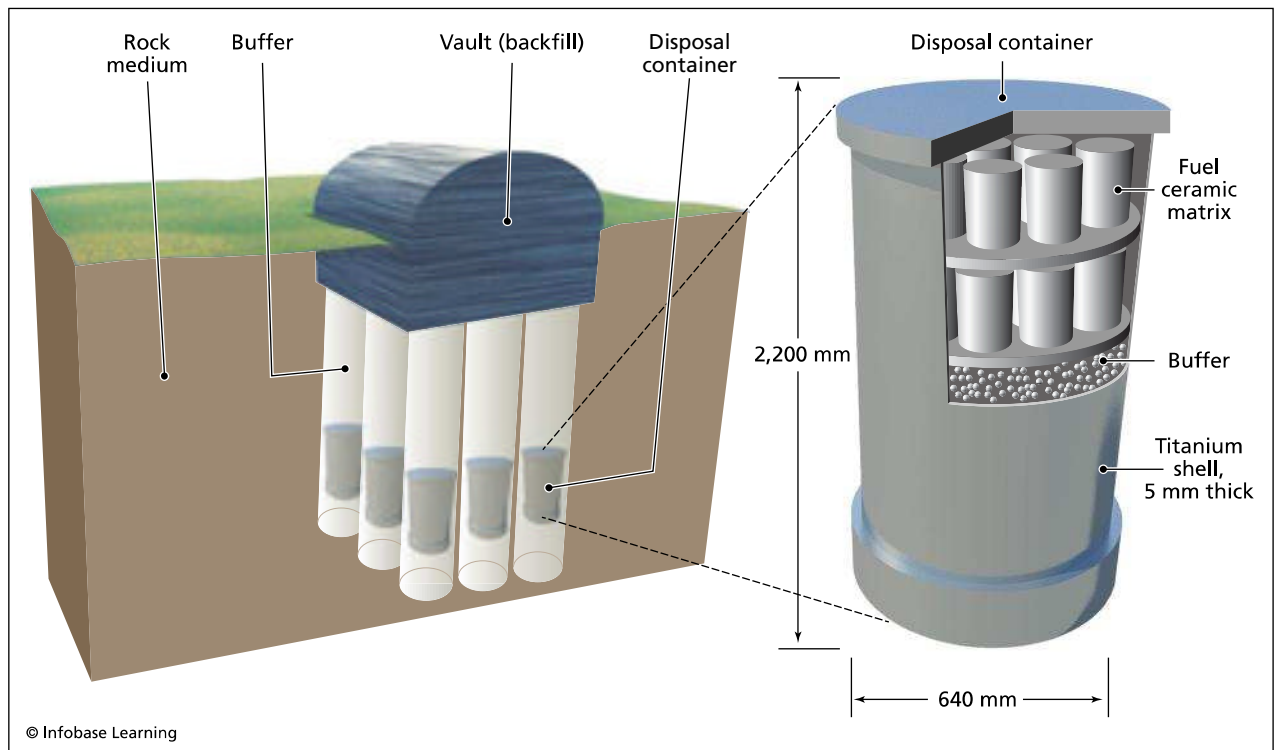


Diagram showing the repository system for high-level nuclear waste that will be used in Yucca Mountain

although rainfall amounts are low now, climate change in the distant future cannot be predicted and may result in increased levels of precipitation, which could increase infiltration into the repository and raise groundwater table elevations.

In March 2005, an investigation by both the DOE and the Department of the Interior found that several U.S. Geological Survey (USGS) hydrologists had exchanged e-mails discussing possible falsification of quality assurance documents on water infiltration research. A subsequent study confirmed the technical soundness of the USGS's infiltration modeling work, but the controversy exemplified the high degree of suspicion and mistrust with which the DOE and its contractors are viewed, especially by Nevadans. To help allay those fears, the DOE has asked that a non-profit consortium of colleges and universities provide independent expert reviews of scientific and technical work being done on Yucca Mountain.

It seemed unlikely, given the time and money spent so far, as well as the growing need for such a facility, that Yucca Mountain would not become the U.S. high-level waste repository. The site had withstood the scientific, technical, legal, and political challenges its opponents have mounted against its use. In 2010, however, President Barack Obama fulfilled one of his campaign promises and directed the DOE to withdraw Yucca Mountain from consideration as a high-level waste disposal site. Numerous lawsuits challenging the legality of the application

withdrawal, because the site was designed by an act of Congress as the nation's high-level waste repository, are currently under way.

*See also* AQUIFER; EARTHQUAKES; RADIOACTIVE WASTE; VOLCANOES.

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# Z

**zinc** Touted as a miracle cure for colds and other health problems, zinc is probably the ultimate substance to contradict the old saying that if a little is good, a lot is better. Like many of the other heavy metals, in trace quantities, zinc is an essential nutrient and an effective health treatment. Zinc is found in virtually all multivitamin supplements. As zinc oxide, it is an effective treatment for skin problems from diaper rash to acne. It is used for prostate health, hair health, and even vision. Zinc is used in its metallic form or mixed with other metals as alloys or in numerous zinc compounds, primarily zinc oxide but also zinc chloride and other zinc salts, zinc sulfide, zinc sulfate, zinc acetate, zinc carbonate, zinc methyl or diethyl, and zinc pyri-thione, among others. On the other hand, in high concentrations, it is an environmental and human health threat. It is found in so many substances—from galvanized metal to paint to coins—that exposure is a foregone conclusion, making it even more dangerous. Zinc and zinc compounds have been identified in 985 of the first 1,662 U.S. Environmental Protection Agency (EPA)–designated Superfund sites (National Priorities List), among the highest percentages of any environmental contaminant. For this reason, zinc was ranked the 74th most dangerous pollutant on the 2007 CERCLA Priority List of Hazardous Substances.

## PROPERTIES, USE, AND PRODUCTION

Zinc is a naturally occurring inorganic element or pollutant that can be found in most rocks and soils throughout the world in various concentrations. The most common mineral form is sphalerite, which is

a zinc sulfide. The use of zinc by humans began by at least 1000 B.C.E., when it was used both as a component of brass and as a medicine. It was first recognized as a separate metal by 1374 in India as the eighth metal known at that time. The first zinc smelter was constructed in 1743, and hot galvanizing as corrosion prevention was invented in 1836. The first zinc production in the United States began in 1850.

In 2007, mine production in the United States was 815,000 tons (740,000 metric tons), having generally decreased from 858,000 tons (780,000 metric tons) in 2002. Imports in 2007 totaled 418,000 tons (380,000 metric tons) of ore and 759,000 tons (693,000 metric tons) of refined zinc, which is about average for the past five years (average 784,400 metric tons). Domestic production was from mines in Alaska, Missouri, Montana, and Washington. Imports of ore are mainly from Peru (62 percent), Australia (18 percent), Ireland (11 percent), and Mexico (8 percent); refined metal is from Canada (63 percent), Mexico (18 percent), and Kazakhstan and Brazil (4 percent each). In 2007, some 462,000 tons (420,000 metric tons) was from waste and scrap, 85 percent of which was from Canada.

In 2006, domestic consumption of zinc was used 55 percent in galvanizing, 21 percent in zinc-based alloys, and 16 percent in brass and bronze, primarily in the metals industry. Zinc compounds were used in agriculture, the chemical industry, paint, and the rubber industry. Zinc is also used in die casting, linoleum, fireworks, glass and ceramics, batteries, fuel cells, coins, wood preservative, and ointments, among other uses.



## ENVIRONMENTAL RELEASE AND FATE

Zinc is released to the environment through numerous point sources and nonpoint sources. It occurs naturally in rocks and soils and is released during volcanic eruptions, which make it ubiquitous in the environment. High-volume anthropogenic zinc releases are primarily from mining and refining, steel and alloy production, coal-fired power plants, and waste incineration, but low-level release is widespread. The industrial releases are primarily to the air in the form of fine dust that may or may not attach to particulate and settle to the ground and surface water or be washed out by precipitation. Zinc is naturally present in soils; high concentrations may result from industrial dumping, but also from residential and municipal sources in the form of solid waste, sludge, and fertilizer. Most zinc attaches to soil particles and remains fixed. Some zinc compounds, however, dissolve under certain conditions, including low pH, and leach into the groundwater system. Most particulate zinc in surface water settles to the bottom and remains fixed in the sediments. Zinc can bioaccumulate in fish.

Annual industrial release of zinc to the environment in the United States is enormous. According to the EPA Toxics Release Inventory (TRI) for 2006, there was a total industrial release of 794,261,212 pounds (361,027,823 kg) for all zinc compounds and 79,379,490 pounds (36,081,586 kg) for zinc fumes or dust.

## HEALTH EFFECTS FROM EXPOSURE

Even though small amounts of zinc are vital to survival, higher amounts can cause myriad adverse health effects, as can certain forms at low amounts. Inhalation exposure to zinc fumes from welding, smelting, and other metallurgy on an acute basis can cause a short-term disease called metal fume fever with zinc shakes or chills. This condition is characterized by flulike symptoms including headache, fever, chills, muscle aches, irritation of the nasal passage, cough, reduced lung capacity, nausea, vomiting, fatigue, gastrointestinal distress, weakness, and tiredness. Inhalation of zinc chloride causes nose and throat irritation, cough, chest pain, pulmonary inflammation and pulmonary fibrosis, headache, nausea, and vomiting. Oral ingestion of high doses of zinc causes nausea, vomiting, diarrhea, and abdominal and possible gastric bleeding. Zinc chloride ingestion causes mouth and throat pain, pharyngitis, esophagitis, and pancreas damage. Zinc phosphide reacts with stomach acid to produce phosphine gas, which causes vomiting, abdominal cramping, leth-

argy, hypotension, cardiac arrhythmia, circulatory collapse, pulmonary edema, convulsions, kidney damage, coma, and death within two weeks. Long-term chronic exposure primarily causes anemia and damage to the pancreas and possibly the kidneys and liver. Laboratory animals also had skin irritation and fertility problems in addition to the problems observed in humans. Zinc is classified in EPA group D, not classified with regard to its potential as a carcinogen. Some studies suggest an increase in lung cancer, lymphoma, and tumors in general in laboratory animals, but none is considered definitive.

## REGULATIONS ON HUMAN EXPOSURE

As a result of its widespread distribution and the potential adverse health effects, zinc exposure is regulated by several federal agencies, but the regulations are probably the least stringent for all of the heavy metals. The EPA limits zinc in drinking water to 5 milligrams per liter or less largely because it affects the taste. They also require the reporting of spills to the National Response Center, but the minimal amount is a large 1,000 pounds (454.5 kg) for the most dangerous of zinc and zinc compounds (zinc phosphide, for example) and 5,000 pounds (2,273 kg) for the rest. The Occupational Safety and Health Administration (OSHA) set a limit of 1 milligram of zinc chloride per cubic meter of workplace air and 5 milligrams of zinc oxide per cubic meter of workplace air for an eight-hour-day, 40-hour workweek. The National Institute of Occupational Safety and Health (NIOSH) sets a limit of 1 milligram of zinc oxide per cubic meter of workplace air for a 10-hour day, 40-hour workweek. The NIOSH National Occupational Exposure Survey of 1981–83 found that many American workers were exposed to many forms of zinc. Some of the exposure levels include 492,366 workers for zinc oxide, 89,451 for zinc sulfate, 79,920 for zinc dust, 56,944 for zinc sulfide, and 26,421 for zinc phosphate.

*See also* INORGANIC POLLUTANTS; POINT SOURCE AND NONPOINT SOURCE POLLUTION; SUPERFUND SITES.

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# APPENDIX I

## LIST OF ACRONYMS

### A

**AA (Atomic Absorption)** a laboratory analytical method commonly used for the detection of metals in soil and groundwater

**AAI (all appropriate inquiry)** due diligence process used to establish “innocent owner” protection status under CERCLA

**AANWR (Alaskan Arctic National Wildlife Refuge)** a protected area possibly containing large amounts of untapped petroleum reserves

**ABEL** the EPA’s computer model for analyzing a violator’s ability to pay a civil penalty

**ACBM** Asbestos-Containing Building Material

**ACFM** Actual Cubic Feet per Minute, a measure of gaseous discharge

**ACGIH** American Conference of Governmental Industrial Hygienists

**ACL (Alternate Concentration Limit)** a risk-based, higher numerical value often proposed by a responsible party as a substitute for a lower (more strict) soil or groundwater cleanup standard

**ACM** Asbestos-Containing Material

**ACO (Administrative Consent Order)** a USEPA and state legal enforcement tool

**ACOE** Army Corps of Engineers

**ACWM** Asbestos-Containing Waste Material

**ADD (Average Daily Dose)** used in risk assessment to calculate safe exposure levels

**ADI (Acceptable Daily Intake)** used in risk assessment to determine acceptable levels of exposure

**AEA** Atomic Energy Act

**AFCEE** Air Force Center for Environmental Excellence

**AGST** Above Ground Storage Tank

**AHERA** Asbestos Hazard Emergency Response Act

**AHM** Acutely Hazardous Material, as defined in RCRA

**AHU** Air Handling Unit

**AI** Active Ingredient

**AL** Acceptable Level

**ALARA** As Low as Reasonably Achievable, a performance based standard related to radiation exposure

**AMSL** Above Mean Sea Level

**AOC** Area of Concern, a location on a site requiring investigation to confirm whether a release of hazardous wastes or substances may have occurred

**APCD** Air Pollution Control District (California)

**API** American Petroleum Institute

**AQI** Air Quality Index

**AQMP** Air-Quality Management Plan

**AR** Administrative Record

**ARAR** Applicable or Relevant and Appropriate Standards, Limitations, Criteria, and Requirements, part of the CERCLA process that defines cleanup standards for a particular Superfund site

**ARCS** Alternative Remedial Contract Strategy, contracting vehicle used by USEPA to authorize Superfund site cleanups

**ASHAA** Asbestos in Schools Hazard Abatement Act

**AST** Aboveground Storage Tank

**ASTHO** Association of State and Territorial Health Officers

**ASTM** American Society for Testing and Materials

**ASTSWMO** Association of State and Territorial Solid Waste Management Officials

**ATCM** Air Toxic Control Measure

**ATSDR** Agency for Toxic Substances and Disease Registry

**AWRA** American Water Resources Association

**AWWA** American Water Works Association

### B

**BACM** Best Available Control Measures, a technology standard required under CWA, CAA, or other federal regulations

- BACT** Best Available Control Technology, a technology standard required under CWA, CAA, or other federal regulations
- BADT** Best Available Demonstrated Technology, a technology standard required under CWA, CAA, or other federal regulations
- BAF** Bioaccumulation Factor, the rate that a contaminant will be incorporated into an organism
- BART** Best Available Retrofit Technology, a technology standard required under CWA, CAA, or other federal regulations
- BAT** Best Available Technology, a technology standard required under CWA, CAA, and/or federal regulations
- BATEA** Best Available Treatment Economically Achievable, a technology standard required under CWA, CAA, or other federal regulations
- BCPCT** Best Conventional Pollutant Control Technology, a technology standard required under CWA, CAA, or other federal regulations
- BCT** Best Control Technology, a technology standard required under CWA, CAA, or other federal regulations
- BDAT** Best Demonstrated Achievable Technology, a technology standard required under CWA, CAA, or other federal regulations
- BDCT** Best Demonstrated Control Technology, a technology standard required under CWA, CAA, or other federal regulations
- BDT** Best Demonstrated Technology, a technology standard required under CWA, CAA, or other federal regulations
- BGL** Below Ground Level
- BGS** Below Ground Surface
- BIF** Boiler and Industrial Furnace
- BIOPLUME** Computer model used to predict the extent of groundwater contamination
- BMP** Best Management Practice(s), a technology standard required under CWA, CAA, and other federal regulations
- BNA** Bureau of National Affairs, an environmental database company
- BOD** Biochemical Oxygen Demand or Biological Oxygen Demand, a measure of water quality
- BPT** Best Practicable Technology, a technology standard required under CWA, CAA, or other federal regulations
- BPWTT** Best Practical Wastewater Treatment Technology, a technology standard required under CWA, CAA, or other federal regulations
- BRAC** Base Realignment and Closure
- BTEX** Benzene, Toluene, Ethylbenzene, Xylene, the principal components of gasoline
- C**
- CAA** Clean Air Act
- CAAA** Clean Air Act Amendments
- CAER** Community Awareness and Emergency Response
- CAIR** Clean Air Interstate Rule
- CAM** Compliance Assurance Monitoring rule
- CAMP** Continuous Air Monitoring Program
- CAMR** Clean Air Mercury Rule
- CAMU** Corrective Action Measures Unit, a specially designed disposal area for wastes generated during the cleanup of an RCRA-regulated site
- CAO** Corrective Action Order, as defined in RCRA
- CAP** Corrective Action Plan
- CAR** Corrective Action Report
- CAS** Chemical Abstract Service
- CBI** Confidential Business Information, as defined in TSCA and other federal regulations
- CCAA** Canadian Clean Air Act
- CCTP** Clean Coal Technology Program
- CDI** Chronic Daily Intake
- CE** Categorical Exclusion, a type of federal action that does not require an EIS under NEPA
- CEC** Cation Exchange Capacity, a measure of a soil's ability to retain positively charged ions (metals). Often used as an indicator of a soil's ability to protect groundwater from contamination
- CEM** Continuous Emission Monitoring, required under the CAA for facilities that violate permit limitations
- CEMS** Continuous Emission Monitoring System
- CEQ** Council on Environmental Quality
- CERCLA** Comprehensive Environmental Response, Compensation, and Liability Act
- CERCLIS** Comprehensive Environmental Response, Compensation, and Liability Information System
- CESQG** Conditionally Exempt Small Quantity Generator, as defined in RCRA
- CFC** Chlorofluorocarbons, chemicals that interfere with the production of ozone in the upper atmosphere
- CFM** Chlorofluoromethanes, chemicals that interfere with the production of ozone in the upper atmosphere
- CFR** Code of federal regulations
- CFS** Cubic Feet per Second
- CGL** Comprehensive General Liability, a type of insurance coverage
- CHP** Certified Health Professional



**CIH** Certified Industrial Hygienist  
**CLP** Contract Laboratory Program  
**CM** Corrective Measure, a cleanup action required under RCRA  
**CMI** Corrective Measures Implementation, a RCRA-regulated cleanup program  
**CMS** Corrective Measure Study, a site investigation performed under RCRA  
**CNG** Compressed Natural Gas  
**CO** Consent Order, a legal enforcement tool used by EPA and the states to force compliance with environmental regulations  
**COC** Chemical of Concern, a possible contaminant in soil or groundwater  
**COD** Chemical Oxygen Demand, a measure of water quality  
**COH** Coefficient of Haze, an indicator of air quality  
**CPF** Carcinogenic Potency Factor, a term used in risk assessments  
**CPOEC** Contaminant of Potential Ecological Concern  
**CSO** Combined Sewer Overflow, when storm water and sanitary wastewater are carried in the same collection system and discharge into the environment without treatment  
**CSP** Certified Safety Professional  
**CWA** Clean Water Act (a.k.a. FWPCA)  
**CWAP** Clean Water Action Project, usually an upgrade to an existing sewage treatment plant funded through the CWA grant program  
**CZMA** Coastal Zone Management Act  
**CZMARA** Coastal Zone Management Act Reauthorization Amendments

## D

**DAF** Dilution Attenuation Factor, a measure of how site-specific conditions may dilute a contaminant once it has been released into the environment  
**DBP** Disinfection By-Product, a group of chemicals regulated under the Safe Drinking Water Act  
**DEC** Department of Environmental Conservation, a state agency responsible for development and enforcement of environmental regulations  
**DEP** Department of Environmental Protection, a state agency responsible for development and enforcement of environmental regulations  
**DEQ** Department of Environmental Quality, a state agency responsible for development and enforcement of environmental regulations  
**DL** Detection Limit, the lowest level that a laboratory method can reliably “see” or detect a contaminant  
**DMR** Discharge Monitoring Report, a regular listing (monthly, quarterly, etc.) of contaminants released into the surface water by a facility with a NPDES permit  
**DNA** Deoxyribonucleic acid  
**DNAPL** Dense Nonaqueous Phase Liquid, a contaminant that forms a layer near the bottom of the water table  
**DO** Dissolved Oxygen, a measure of water quality  
**DOD** Department of Defense  
**DOE** Department of Energy  
**DOI** Department of Interior  
**DOJ** Department of Justice  
**DOT** Department of Transportation  
**DPT** Direct Push Technology, a method used to drill shallow soil borings by using a vibrating hammer to drive or “push” a hollow steel sampling tube into the ground  
**DQO** Data Quality Objectives  
**DRE** Destruction and Removal Efficiency, a performance standard established in the CAA  
**DRO** Diesel Range Organics, a class of contaminants originating from a release of heavier, less refined petroleum products (diesel fuel or heating oil)  
**DSCF** Dry Standard Cubic Feet, a measure of gaseous discharge  
**DSCM** Dry Standard Cubic Meter  
**DTB** Depth To Bottom, usually used to signify the depth to which a boring or monitor well has been drilled  
**DTP** Depth to Product, the distance from the top of a monitoring well or boring to the depth below grade at which a separate phase contaminant (e.g., floating oil) is present in the groundwater  
**DTW** Depth to Water, the distance from the top of a boring or monitoring well to the top of the water table  
**DWS** Drinking Water Standard, as defined in the CWA

## E

**EA** Endangerment Assessment, as described in CERCLA  
**EA** Environmental Assessment, as described in NEPA  
**EA** Environmental Audit  
**EAF** Electric Arc Furnaces  
**EAO** Emergency Administrative Order  
**EAP** Environmental Action Plan  
**EC** Effective Concentration, used in risk assessment to calculate potential exposure rates

- ED** Effective Dose
- EDD** Enforcement Decision Document, the basis for a regulatory action (ACO)
- EDF** Environmental Defense Fund
- EDRS** Enforcement Document Retrieval System
- EDTA** Ethylenediaminetetraacetic Acid
- EER** Excess Emission Reports
- EF** Emission Factor, as defined in CAA
- EGR** Exhaust Gas Recirculation, a type of air pollution control technology
- Eh** Redox Potential, a measure of water's oxidizing capacity
- EHS** Extremely Hazardous Substance, as defined in RCRA
- EI** Emissions Inventory, as defined in CAAA
- EIA** Environmental Impact Assessment, as defined in NEPA
- EIL** Environmental Impairment Liability, a type of insurance policy
- EIR** Environmental Impact Report
- EIS** Environmental Impact Statement, as defined in NEPA
- EJ** Environmental Justice
- EL** Exposure Level
- ELI** Environmental Law Institute
- ELR** Environmental Law Reporter
- EM** Electromagnetic Conductivity, a technique used to detect buried metal objects
- EMR** Environmental Management Report
- EMS** Enforcement Management System
- EMSL** Environmental Monitoring Support Systems Laboratory
- EO** Ethylene Oxide
- EOB** End of Boring, the depth below grade at which subsurface drilling ceased
- EOP** End of Pipe, a discharge point defined by the CWA
- EOT** Emergency Operations Team
- EPA** Environmental Protection Agency, branch of federal government responsible for developing and enforcing environmental laws and policies
- EPACT** Environmental Policy Act
- EPA ID #** Identifier assigned to a generator of hazardous waste by USEPA
- EPC** Exposure Point Concentration, a risk assessment uptake parameter
- EPCRA** Emergency Planning and Community Right to Know Act (SARA)
- EPI** Environmental Policy Institute
- EPRI** Electric Power Research Institute
- EPTC** Extraction Procedure Toxicity Characteristic
- ERC** Environmental Research Center, also Emissions Reduction Credit, as defined in CAA
- ERCS** Emergency Response Cleanup Services, a contracting vehicle used by USEPA to investigate and remediate Superfund sites
- ERL** Environmental Research Laboratory
- ERNS** Emergency Response Notification System
- ERT** Emergency Response Team
- ES** Enforcement Strategy
- ESA** Endangered Species Act; also Environmental Site Assessment, as defined in CERCLA
- ESCA** Electron Spectroscopy for Chemical Analysis, a laboratory analytical method
- ES&H** Environmental Safety and Health, a general term used by many companies to describe the functional part of their organization responsible for environmental and safety compliance
- ESP** Electrostatic Precipitators, an air pollution control device
- ET** Emissions Trading, as defined in CAAA
- ETP** Emissions Trading Policy, as defined in CAAA
- ETS** Emissions Tracking System
- F**
- FBC** Fluidized Bed Combustion, a type of incinerator
- FCAA** Federal Clean Air Act
- FCC** Fluid Catalytic Converter, an air treatment technology
- FDA** Food and Drug Administration
- FDf** Fundamentally Different Factors, as defined in the CWA
- FE** Fugitive Emissions, as defined in the CAA
- FEMA** Federal Emergency Management Agency
- FEPCA** Federal Environmental Pesticide Control Act; enacted as amendments to FIFRA
- FERC** Federal Energy Regulatory Commission
- FFDCA** Federal Food, Drug, and Cosmetic Act
- FGD** Flue-Gas Desulfurization, a type of air pollution treatment technology
- FID** Flame Ionization Detector, a laboratory instrument
- FIFRA** Federal Insecticide, Fungicide, and Rodenticide Act
- FIM** Friable Insulation Material, a type of ACM
- FIP** Final Implementation Plan, as defined in CAA
- FLP** Flash Point
- FLPMA** Federal Land Policy and Management Act
- FML** Flexible Membrane Liner, used in landfills to control leachate migration
- FOIA** Freedom of Information Act
- FONSI** Finding of No Significant Impact, as defined in NEPA
- FP** Fine Particulate, a type of air pollutant
- FPA** Federal Pesticide Act

**FPD** Flame Photometric Detector, a laboratory instrument

**FPPA** Federal Pollution Prevention Act

**FQPA** Food Quality Protection Act

**FR** Federal Register

**FS** Feasibility Study, as defined in CERCLA

**FSA** Food Security Act

**FSP** Field Sampling Plan, methodologies to collect representative samples of soil, groundwater, and other types of media

**FTP** Federal Test Procedure for motor vehicle emissions

**FWCA** Fish and Wildlife Coordination Act

**FWPCA** Federal Water Pollution and Control Act (a.k.a. CWA)

**FY** Fiscal Year

## G

**GAC** Granular Activated Carbon, used in treatment of contaminated water and air

**GACT** Granular Activated Carbon Treatment

**GC** Gas Chromatograph, may be dual-flame or electron capture

**GC/MS** Gas Chromatograph/Mass Spectrograph, a laboratory analytical instrument

**GEP** Good Engineering Practice, a management standard defined in CWA, CAA, and other federal regulations

**GIS** Geographic Information Systems

**GLC** Gas Liquid Chromatography, a laboratory analytical instrument; also Ground Level Concentration, a term used in risk assessment

**GLERL** Great Lakes Environmental Research Laboratory

**GLP** Good Laboratory Practices, a management standard for the operation of an analytical laboratory

**GOCO** Government-Owned/Contractor-Operated, a contracting system for the operation of federal facilities

**GOGO** Government-Owned/Government-Operated

**GOPO** Government-Owned/Private-Operated

**GPAD** Gallons per acre per day

**GPM** Gallons per Minute, a measure of discharge

**GPR** Ground-Penetrating Radar

**GPS** Global Positioning System, satellite location system

**GRO** Gasoline Range Organics, types of constituents found in soil and groundwater as a result of a release of gasoline into the environment

**GWDR** Ground Water Disinfection Rule, as defined in the CWA

**GWM** Groundwater Monitoring

**GWP** Global Warming Potential

**GWPS** Groundwater Protection Standard, as defined in the CWA

## H

**HA** Health Advisory, as defined in the SDWA

**HAP** Hazardous Air Pollutant, as defined in the CAA

**HAZMAT** Hazardous Materials, as defined in RCRA and CERCLA

**HAZOP** Hazard and Operability Study

**HBFC** Hydrobromofluorocarbon, an ozone depleting substance

**HC** Hazardous Constituents; also Hydrocarbon

**HCCPD** Hexachlorocyclopentadiene

**HCFC** Hydrochlorofluorocarbon, an ozone depleting substance

**HCS** Hazard Communication Standard, as defined by OSHA

**HDPE** High-Density Polyethylene

**HDT** Highest Dose Tested, in a study

**HEAL** Human Exposure Assessment Location, a term used in risk assessment

**HEPA** High-Efficiency Particulate Air, a type of air pollution control device

**HFC** Hydrofluorocarbon

**HHE** Human Health and the Environment, a general term used to describe protectiveness of an environmentally related action

**HHRA** Human Health Risk Assessment

**HHV** Higher Heating Value

**HHW** Household Hazardous Waste

**HI** Hazard Index, a term used in risk assessment

**HLRW** High-Level Radioactive Waste

**HMIS** Hazardous Materials Information System

**HMRT** Hazardous Materials Response Team

**HMS** Hazardous Materials Storage

**HMTA** Hazardous Materials Transportation Act

**HMTC** Hazardous Materials Technology Center, part of DOT

**HMTR** Hazardous Materials Transportation Regulations

**HOC** Halogenated Organic Carbons

**HON** Hazardous Organic NESHAP, as defined in the CAA

**HOV** High-Occupancy Vehicle

**HP** Horsepower

**HPLC** High-Performance Liquid Chromatography, a laboratory analytical procedure

**HPV** High-Priority Violator, a term used in federal legal enforcement actions

**HRA** Health Risk Assessment

**HRS** Hazardous Ranking System or Score, as defined in CERCLA

**HS** Hazardous Substance  
**HSL** Hazardous Substance List, as defined in CERCLA and RCRA  
**HSWA** Hazardous and Solid Waste Amendments, as related to RCRA  
**HVAC** Heating, Ventilation, and Air-Conditioning system  
**HW** Hazardous Waste  
**HWIR** Hazardous Waste Identification Rule, as defined in RCRA  
**HWLT** Hazardous Waste Land Treatment, as defined in RCRA  
**HWM** Hazardous Waste Management, a general term used to describe overall procedures for the control of a company's or facility's waste streams  
**HWMU** Hazardous Waste Management Unit, as defined by RCRA

## I

**IA** Interagency Agreement, an agreement between federal agencies to perform an action  
**IAP** Indoor Air Pollution  
**IAQ** Indoor Air Quality  
**IARC** International Agency for Research on Cancer  
**ICAP** Inductively Coupled Argon Plasma, a laboratory analytical instrument  
**ICBN** International Commission on the Biological Effects of Noise  
**ICCP** International Climate Change Partnership  
**ICP** Inductively Coupled Plasma, a laboratory analytical instrument for inorganic materials  
**ICP-MS** Inductively Coupled Plasma—Mass Spectrometer, for inorganic trace elements  
**ICR** Information Collection Rule, as defined in SDWA  
**ICRE** Ignitability, Corrosivity, Reactivity, Extraction, as described in RCRA  
**ICRP** International Commission on Radiological Protection  
**ICWM** Institute for Chemical Waste Management  
**IDLH** Immediately Dangerous to Life and Health  
**IDW** Investigation Derived Waste, material generated during a site investigation (e.g., drill cutting or used protective clothing)  
**IEB** International Environment Bureau  
**IES** Institute for Environmental Studies  
**IFB** Invitation for Bid, part of the federal procurement process  
**IFCS** International Forum on Chemical Safety  
**IGCI** Industrial Gas Cleaning Institute  
**IJC** International Joint Commission (on Great Lakes)  
**I/M** Inspection/Maintenance  
**IMS** Ion Mobility Spectrometry, a laboratory analytical procedure  
**IOB** Iron Ore Beneficiation, process used to increase iron concentration of an ore  
**IOU** Input/Output Unit  
**IP** Inhalable Particle, a type of air pollution  
**IPCC** Intergovernmental Panel on Climate Change  
**IPCC** Intergovernmental Panel on Climate Control  
**IPCS** International Program on Chemical Safety  
**IPM** Integrated Pest Management  
**IRA** Interim Removal Action, as defined in CERCLA  
**IRIS** Integrated Risk Information System, a catalog of chemical health effects used by EPA in risk assessments  
**IRM** Intermediate Remedial Measures, as defined in CERCLA  
**IRP** Installation Restoration Program for military bases  
**IRPTC** International Register of Potentially Toxic Chemicals  
**IRR** Institute of Resource Recovery  
**IS** Interim Status for a TSDF, as defined in RCRA  
**ISE** Ion-Specific Electrode, a type of analytical instrument for elemental concentrations  
**ISO** International Organization for Standardization  
**ISV** In Situ Vitrification, a process to treat soil containing hazardous wastes  
**ITC** Innovative Technology Council  
**ITC** Interagency Testing Committee  
**ITRC** Interstate Technology Regulatory Coordination  
**IWS** Ionizing Wet Scrubber, a type of air pollution control device

## J

**JECFA** Joint Expert Committee of Food Additives  
**JEIOG** Joint Emissions Inventory Oversight Group  
**JLC** Justification for Limited Competition, part of the federal procurement process  
**JNCP** Justification for Non-Competitive Procurement, part of the federal procurement process  
**JOFOC** Justification for Other than Full and Open Competition, part of the federal procurement process  
**JPA** Joint Permitting Agreement, between federal agencies  
**JTU** Jackson Turbidity Unit, a measure of water quality

## L

**LADD** Lifetime Average Daily Dose; Lowest Acceptable Daily Dose, terms used in risk assessment



- LAER** Lowest Achievable Emission Rate, as defined in CAA
- LBP** Lead-Based Paint
- LC** Lethal Concentration, a term used in risk assessment
- LC** Liquid Chromatography, a laboratory analytical instrument
- LCD** Local Climatological Data
- LCRS** Leachate Collection and Removal System
- LD** Land Disposal
- LD10** Lethal Dose 10 percent, the lowest dosage of a toxic substance that kills test organisms
- LD50** Lethal Dose 50 percent, the dose at which 50 percent of the test subjects die
- LDAR** Leak Detection and Repair, used for underground storage tank systems
- LDC** London Dumping Convention in ocean waters
- LDCRS** Leachate Detection, Collection, and Removal System
- LDR** Land Disposal Restrictions, as defined in RCRA
- LDS** Leak Detection System, for underground storage tank systems
- LEA** Local Enforcement Agency
- LEL** Lowest Effect Level, a term used in risk assessment
- LEL** Lower Explosive Limit for gaseous contaminants
- LEPC** Local Emergency Planning Committee, as defined in SARA
- LERC** Local Emergency Response Committee, as defined in SARA
- LEV** Low Emissions Vehicle, as defined in CAA
- LFG** Landfill Gas
- LFL** Lower Flammability Limit for gaseous contaminants
- LIMB** Limestone-Injection Multistage Burner, a type of incinerator
- LLRW** Low-Level Radioactive Waste
- LMFBR** Liquid Metal Fast Breeder Reactor
- LNAPL** Light Nonaqueous Phase Liquid, a type of contaminant that floats on top of the water table
- LOAEL** Lowest Observed Adverse Effect Level, a term used in risk assessment
- LQG** Large Quantity Generator, as defined in RCRA
- LUFT** Leaking Underground Fuel Tank
- LULU** Locally Unwanted Land Use, a land use that may be beneficial for the region (e.g., prison) but is not wanted by those living near it
- LUST** Leaking Underground Storage Tank
- M**
- MAC** Mobile Air Conditioner
- MACT** Maximum Achievable Control Technology, as defined in CAA
- MAER** Maximum Allowable Emission Rate, as defined in CAA
- MARPOL** International Convention for the Prevention of Pollution from Ships
- MATC** Maximum Acceptable Toxic Concentration, a term used in risk assessment
- MBAS** Methylene-Blue-Active Substances, a type of water pollutant
- mcg/L** micrograms per liter, a measure of concentration
- MCL** Maximum Contaminant Level, as defined in SDWA
- MCLG** Maximum Contaminant Level Goal, as defined in SDWA
- mcg/m<sup>3</sup>** micrograms per cubic meter, a measure of contamination in air
- MCS** Multiple Chemical Sensitivity, a term used in risk assessment
- MDL** Method Detection Limit, the lowest contaminant concentration that an analytical method can reliably detect or “see” in a sample
- MEI** Maximally (or Most) Exposed Individual, a term used in risk assessment
- MEP** Multiple Extraction Procedure, a laboratory analytical procedure
- MGD** Millions of Gallons per Day, a measure of discharge
- mg/kg** milligrams per kilogram or ppm, a measure of concentration in solids
- mg/L** milligrams per liter or ppm, a measure of concentration in liquids
- mg/m<sup>3</sup>** milligrams per cubic meter, a measure of concentration in gases
- MGP** Manufactured Gas Plant
- MNA** Monitored Natural Attenuation, a nonactive approach to groundwater remediation
- MOE** Margin of Exposure, a term used in risk assessment
- MOS** Margin of Safety, a term used in risk assessment
- MOU** Memorandum of Understanding, agreement between two governmental agencies or a governmental agency and private party perform some action
- MP** Melting Point
- MPI** Maximum Permitted Intake, a term used in risk assessment
- MPN** Maximum Possible Number, a term used in microbiological analysis
- MPRSA** Marine Protection, Research and Sanctuaries Act
- MRBMA** Mercury-Containing and Rechargeable Battery Management Act

**MRF** Materials Recovery Facility, a type of recycling center  
**MRL** Maximum-Residue Limit, a measure of pesticide tolerance  
**MS** Mass Spectrometer  
**MSDS** Material Safety Data Sheet, as defined by OSHA  
**MSW** Municipal Solid Waste  
**MTD** Maximum Tolerated Dose, a term used in risk assessment  
**MW** Monitoring Well

## N

**NAA** Nonattainment Area, as defined in CAA  
**NAAQS** National Ambient Air Quality Standards, as defined in CAA  
**NAMS** National Air Monitoring Stations  
**NAPAP** National Acid Precipitation Assessment Program  
**NAPL** Nonaqueous Phase Liquid, a separate layer of contaminant that either sinks or floats within the water table  
**NAS** National Academy of Sciences  
**NASA** National Aeronautics and Space Administration  
**NASDA** National Association of State Departments of Agriculture  
**NCAMP** National Coalition against the Misuse of Pesticides  
**NCP** National Contingency Plan, procedures to be used for the investigation and cleanup of CERCLA designated sites  
**NCWS** Non-Community Water System, as defined in SDWA  
**ND** Not Detected; lowest concentration of a contaminant that can be reliably detected or seen by a laboratory's analytical instrument  
**NEPA** National Environmental Policy Act  
**NEPI** National Environmental Policy Institute  
**NESHAP** National Emission Standard for Hazardous Air Pollutants  
**NETA** National Environmental Training Association  
**NFA** No Further Action, a regulatory determination that site investigation or cleanup goals have been achieved  
**NFRAP** No Further Remedial Action Planned, the end of cleanup activities at a site  
**NIEHS** National Institute for Environmental Health Sciences  
**NIOSH** National Institute of Occupational Safety and Health  
**NIPDWR** National Interim Primary Drinking Water Regulations, as defined in SDWA  
**NOAA** National Oceanographic and Atmospheric Agency  
**NOAEL** No Observable Adverse Effect Level, a term used in risk assessment  
**NOEL** No Observable Effect Level, a term used in risk assessment  
**NOV** Notice of Violation, used to notify a facility that a violation of an environmental regulation has occurred  
**NORM** Naturally Occurring Radioactive Material  
**NPDES** National Pollutant Discharge Elimination System, as defined in CWA  
**NPHAP** National Pesticide Hazard Assessment Program  
**NPIRS** National Pesticide Information Retrieval System  
**NPL** National Priorities List, as defined by CERCLA  
**NRC** U.S. Nuclear Regulatory Commission; also National Response Center (CERCLA)  
**NRD** Natural Resource Damage  
**NRDC** Natural Resources Defense Council  
**NSDWR** National Secondary Drinking Water Regulations, as defined in SDWA  
**NSPS** New Source Performance Standards, as defined in CAA  
**NSR** New Source Review, as defined in CAA  
**NSR/PSD** National Source Review/Prevention of Significant Deterioration, as defined in CAA  
**NTI** National Toxics Inventory  
**NTIS** National Technical Information Service, government publishing center  
**NTNCWS** Non-Transient Non-Community Water System, as defined in SDWA  
**NTP** National Toxicology Program  
**NTU** Nephelometric Turbidity Unit, a measure of water quality  
**NWPA** Nuclear Waste Policy Act

## O

**ODP** Ozone-Depleting Potential  
**ODS** Ozone-Depleting Substances  
**OECD** Organization for Economic Cooperation and Development  
**OEHA** Office of Environmental Health Hazard Assessment (USEPA)  
**OERR** Office of Emergency and Remedial Response (USEPA)  
**O&M** Operations and Maintenance  
**ONWI** Office of Nuclear Waste Isolation  
**OPA** Oil Pollution Act of 1990  
**ORE** Office of Regulatory Enforcement  
**ORC** Oxygen Release Compound, a groundwater remediation technology  
**ORM** Other Regulated Material, as defined in HMTA  
**ORP** Oxidation-Reduction Potential, a measure of water chemistry

**OSHA** Occupational Safety and Health Administration  
**OSWER** Office of Solid Waste and Emergency Response (USEPA)  
**OTA** Office of Technology Assessment, U.S. Congress  
**OTAG** Ozone Transport Assessment Group  
**OTC** Ozone Transport Commission  
**OTIS** Online Tracking Information System  
**OU** Operable Unit, as defined by CERCLA  
**OVA** Organic Vapor Analyzer  
**OVM** Organic Vapor Meter

## P

**P2** Pollution Prevention  
**PAG** Pesticide Assignment Guidelines  
**PAI** Performance Audit Inspection, as defined in CWA  
**PAM** Pesticide Analytical Manual  
**PA/SI** Preliminary Assessment/Site Investigation, as defined in CERCLA  
**PAT** Permit Assistance Team, as defined in RCRA  
**PATS** Pesticide Action Tracking System  
**PBT** Persistent Bioaccumulative Toxic pollutants  
**PCM** Phase Contrast Microscopy, an asbestos detection method  
**PCO** Pest Control Operator  
**PCSD** President's Council on Sustainable Development  
**PE** Professional Engineer, as licensed by an individual state or other nonfederal jurisdiction  
**PEL** Permissible Exposure Limit, as defined by OSHA  
**PG** Professional Geologist, as licensed by an individual state or other nonfederal jurisdiction  
**PHC** Principal Hazardous Constituent; also Petroleum Hydrocarbon  
**PHSA** Public Health Service Act  
**PIC** Products of Incomplete Combustion  
**PID** Photoionization Detector  
**PIGS** Pesticides in Groundwater Strategy  
**PIMS** Pesticide Incident Monitoring System  
**PIN** Pesticide Information Network  
**PIP** Public Involvement Program  
**PIRG** Public Interest Research Group  
**PIT** Permit Improvement Team  
**PLIRRA** Pollution Liability Insurance and Risk Retention Act  
**PLM** Polarized Light Microscopy  
**PM** Particulate Matter, a common air pollutant  
**PM<sub>2.5</sub>** Particulate Matter smaller than 2.5  $\mu\text{m}$  in diameter  
**PM<sub>10</sub>** Particulate Matter nominally 10  $\mu\text{m}$  and less in diameter  
**PM<sub>15</sub>** Particulate Matter nominally 15  $\mu\text{m}$  and less in diameter  
**PMEL** Pacific Marine Environmental Laboratory  
**PMN** Premanufacture Notification, as defined in TSCA  
**PMNF** Premanufacture Notification Form, as defined in TSCA  
**PNA** Polynuclear Aromatic Hydrocarbons  
**POC** Point of Compliance, as defined in RCRA  
**POE** Point of Exposure, a term used in risk assessment  
**POGO** Privately-Owned/Government-Operated  
**POHC** Principal Organic Hazardous Constituent  
**POM** Particulate Organic Matter; also Polycyclic Organic Matter  
**POP** Persistent Organic Pollutant  
**POTW** Publicly Owned Treatment Works, a municipal sewage treatment plant  
**POV** Privately Owned Vehicle  
**PPA** Pollution Prevention Act  
**ppb** parts per billion, a measure of concentration  
**PPE** Personal Protective Equipment  
**PPIC** Pesticide Programs Information Center  
**PPIS** Pesticide Product Information System  
**ppm** parts per million/parts per billion, a measure of concentration  
**ppmv** parts per million, by volume  
**ppmw** parts per million, by weight  
**PPSP** Power Plant Siting Program  
**ppt** parts per trillion, a measure of concentration  
**ppth** parts per thousand, a measure of concentration  
**PRA** Paperwork Reduction Act  
**PRATS** Pesticides Regulatory Action Tracking System  
**PRG** Preliminary Remediation Goal  
**PRN** Pesticide Registration Notice as defined in FIFRA  
**PRP** Potentially Responsible Party, as defined by CERCLA  
**PRZM** Pesticide Root Zone Model, as defined in FIFRA  
**PS** Point Source, as defined in CWA  
**PSA** Preliminary Site Assessment  
**PSC** Program Site Coordinator  
**PSD** Prevention of Significant Deterioration, as defined in CAA  
**PSES** Pretreatment Standards for Existing Sources, as defined in CWA  
**psi** pounds per square inch, a measure of pressure  
**psig** pressure per square inch gauge  
**PSM** Point Source Monitoring; also Process Safety Management  
**PSNS** Pretreatment Standards for New Sources, as defined in CAA  
**PTE** Potential to Emit, as defined in CAA  
**PTFE** Polytetrafluoroethylene (Teflon)  
**PUC** Public Utility Commission

**PVC** Polyvinyl Chloride  
**PWB** Printed Wiring Board  
**PWS** Public Water Supply/System  
**PWSS** Public Water Supply System

## Q

**QAC** Quality Assurance Coordinator  
**QAMIS** Quality Assurance Management and Information System  
**QAO** Quality Assurance Officer  
**QAPP** Quality Assurance Program (or Project) Plan  
**QA/QC** Quality Assistance/Quality Control  
**QAT** Quality Action Team  
**QBTU** Quadrillion British Thermal Units  
**QC** Quality Control  
**QCA** Quiet Communities Act  
**QCI** Quality Control Index  
**QCP** Quiet Community Program  
**QL** Quantification Limit, a laboratory instrument performance standard  
**QNCR** Quarterly Noncompliance Report  
**QUA** Qualitative Use Assessment

## R

**RA** Reasonable Alternative or Regulatory Alternatives or Regulatory Analysis or Remedial Action or Resource Allocation or Risk Analysis or Risk Assessment  
**RAATS** RCRA Administration Action Tracking System  
**RAC** Radiation Advisory Committee; Response Action Coordinator  
**RACM** Reasonably Available Control Measures, as defined in CAA  
**RACT** Reasonably Available Control Technology, as defined in CAA  
**rad** Radiation Absorbed Dose, a unit of measurement of radiation absorbed by humans  
**RAGS** Risk Assessment Guidelines for Superfund  
**RAMP** Rural Abandoned Mine Program  
**RAMS** Regional Air Monitoring System  
**RAO** Remedial Action Outcome  
**RAP** Remedial Action Plan, as defined in CERCLA  
**RAW** Remedial Action Workplan; also Removal Action Workplan  
**RBCA** Risk Based Corrective Action, a procedure to establish site-specific soil or groundwater cleanup standards  
**RC** Recovery Well, used in the extraction and treatment of contaminated groundwater  
**RCC** Radiation Coordinating Council  
**RCRA** Resource Conservation and Recovery Act  
**RCRIS** Resource Conservation and Recovery Information System  
**R&D** Research and Development  
**RD&D** Research, Development and Demonstration

**RDF** Refuse-Derived Fuel  
**RD/RA** Remedial Design/Remedial Action  
**RDV** Reference Dose Values, a term used in risk assessment  
**RDX** Research Derived Explosive  
**RE** Reasonable Efforts, a regulatory compliance term  
**REA** Registered Environmental Auditor (California)  
**REE** Rare Earth Elements  
**REEP** Review of Environmental Effects of Pollutants  
**REL** Recommended Exposure Limits or Levels; also Reference Exposure Level, terms used in risk assessment  
**REM** Roentgen Equivalent Man, a measure of radioactive dose  
**REM/FIT** Remedial/Field Investigation Team  
**REMS** RCRA Enforcement Management System  
**RF** Response Factor, a term used in risk assessment  
**RFA** Regulatory Flexibility Act or RCRA Facility Assessment  
**RFB** Request for Bid  
**RfC** Reference Concentration, a term used in risk assessment  
**RfD** Reference Dose Value, a term used in risk assessment  
**RFI** Remedial Field Investigation, as defined in RCRA  
**RFP** Request for Proposal  
**RHRS** Revised Hazard Ranking System, as defined in CERCLA  
**RI** Reconnaissance Inspection  
**RI** Remedial Investigation, as defined in CERCLA  
**RIA** Regulatory Impact Assessment  
**RIC** Radon Information Center  
**RICO** Racketeer Influenced and Corrupt Organizations Act  
**RI/FS** Remedial Investigation/ Feasibility Study, as defined in CERCLA  
**RIP** RCRA Implementation Plan  
**RISC** Regulatory Information Service Center  
**RJE** Remote Job Entry  
**RLL** Rapid and Large Leakage, a descriptor for release rates into the environment  
**RMCL** Recommended Maximum Contaminant Level, phrase being discontinued in favor of MCLG, as defined in SDWA  
**RME** Reasonable Maximum Exposure, a term used in risk assessment  
**RMP** Risk Management Plan  
**RNA** Ribonucleic Acid  
**ROADWAY** A computer model to predict pollutant concentrations near a roadway  
**ROC** Record of Communication  
**ROD** Record of Decision, as defined in CERCLA  
**ROG** Reactive Organic Gases  
**ROMCOE** Rocky Mountain Center on Environment



**ROP** Rate of Progress, a regulatory enforcement term

**ROPA** Record of Procurement Action, a government contracting term

**ROSA** Regional Ozone Study Area

**RP** Respirable Particulates or Responsible Party

**RQ** Reportable Quantities, as defined in CERCLA

**RQG** Reduced Quantity Generator, as defined by RCRA

**RRC** Regional Response Center

**RRT** Regional Response Team

**RSD** Risk-Specific Dose, a term used in risk assessment

**RTECS** Registry of Toxic Effects of Chemical Substances

**RTK** Right to Know

**RTP** Research Triangle Park

**RUP** Restricted Use Pesticide, as defined in FIFRA

**RWC** Residential Wood Combustion

## S

**S&A** Sampling and Analysis or Surveillance and Analysis

**SAB** Science Advisory Board

**SAC** Suspended and Cancelled Pesticides, as defined in FIFRA

**SAEWG** Standing Air Emissions Work Group

**SAIC** Special Agents in Charge

**SANE** Sulfur and Nitrogen Emissions

**SAP** Scientific Advisory Panel or Sampling and Analysis Plan

**SARA** Superfund Amendments and Reauthorization Act of 1986

**SAV** Submerged Aquatic Vegetation

**SCD/SWDC** Soil or Soil and Water Conservation District

**SCFM** Standard Cubic Feet per Minute

**SCR** Selective Catalytic Reduction, an air pollution control technology

**SCRC** Superfund Community Relations Coordinator

**SCSA** Soil Conservation Society of America

**SCSP** Storm and Combined Sewer Program

**SDWA** Safe Drinking Water Act

**SDWIS** Safe Drinking Water Information System

**SBS** Sick Building Syndrome

**SEA** State Enforcement Agreement

**SEA** State/EPA Agreement

**SEAM** Surface, Environment, and Mining

**SEAS** Strategic Environmental Assessment System

**SEDS** State Energy Data System

**SEIA** Socioeconomic Impact Analysis, as defined in NEPA

**SEM** Standard Error of the Means, a statistical measure of data quality

**SEP** Supplementary Environmental Project

**SEPC** State Emergency Planning Commission

**SEPWC** Senate Environment and Public Works Committee

**SETAC** Society for Environmental Toxicology and Chemistry

**SETS** Site Enforcement Tracking System

**SF** Standard Form or Superfund or Safety Factor

**SFA** Spectral Flame Analyzer, a laboratory analytical instrument

**SFFAS** Superfund Financial Assessment System

**SFIREG** State FIFRA Issues Research and Evaluation Group

**SHWL** Seasonal High Water Level

**SI** International System of Units or Site Inspection

**SIC** Standard Industrial Classification

**SICEA** Steel Industry Compliance Extension Act

**SIMS** Secondary Ion–Mass Spectrometry

**SIP** State Implementation Plan, as defined in CAA

**SITE** Superfund Innovative Technology Evaluation

**SLAMS** State/Local Air Monitoring Station

**SMCL** Secondary Maximum Contaminant Level, as defined in SDWA

**SMCRA** Surface Mining Control and Reclamation Act

**SME** Subject Matter Expert

**SMOA** Superfund Memorandum of Agreement

**SNAAQs** Secondary National Ambient Air Quality Standards, as defined in CAA

**SNARL** Suggested No Adverse Response Level, a term used in risk assessment

**SNC** Significant Noncompliers, a regulatory enforcement term

**SNUR** Significant New Use Rule, as defined in TSCA

**SOC** Synthetic Organic Chemicals

**SOCMI** Synthetic Organic Chemicals Manufacturing Industry

**SOW** Scope of Work

**SPCC** Spill Prevention, Containment, and Countermeasure, as defined in CWA

**SPE** Secondary Particulate Emissions, as defined in CAA

**SPLMD** Soil-pore Liquid Monitoring Device, a site characterization tool

**SPLP** Synthetic Precipitation Leaching Procedure, a laboratory method to test the leachability of contaminants from soil or solid waste

**SPS** State Permit System

**SQBE** Small Quantity Burner Exemption, as defined in RCRA

**SQG** Small Quantity Generator, as defined in RCRA

**SRAP** Superfund Remedial Accomplishment Plan

**SRC** Solvent-Refined Coal

- SRF** State Revolving Fund, as defined in CWA or SDWA
- SRM** Standard Reference Method, a compendium of laboratory analytical procedures
- SS** Setttable Solids or Suspended Solids
- SSA** Sole Source Aquifer
- SSAC** Soil Site Assimilated Capacity
- SSC** State Superfund Contracts
- SSEIS** Stationary Source Emissions and Inventory System, as defined in CAA
- SSO** Sanitary Sewer Overflow
- SSL** Soil Screening Levels, a term used in setting site-specific risk assessments
- STALAPCO** State and Local Air-Pollution Control Officials
- STAPPA** State and Territorial Air Pollution Program Administrators
- STAR** State Acid Rain projects
- STEL** Short Term Exposure Limit, as defined by OSHA
- STEM** Scanning Transmission-Electron Microscope
- STN** Scientific and Technical Information Network
- STORET** Storage and Retrieval of Water-Related Data
- STP** Sewage Treatment Plant or Standard Temperature and Pressure
- SUD** Safe Use Determination, as defined by TSCA
- SUP** Standard Unit of Processing
- SV** Sampling Visit or Significant Violator, regulatory enforcement terms
- SVE** Soil Vapor Extraction, a soil remedial technology
- SVOC** Semivolatile Organic Compounds
- SWA** Solid Waste Act; also known as RCRA
- SWAP** Source Water Assessment Program
- swarf** solid waste from metal grinding process
- SWC** Settlement with Conditions, a regulatory enforcement term
- SWDA** Solid Waste Disposal Act
- SWIE** Southern Waste Information Exchange
- SWMP** Storm Water Monitoring Program
- SWMU** Solid Waste Management Unit, as defined in RCRA
- SWPA** Source Water Protection Area, as defined in SDWA
- SWPPP** Storm Water Pollution Prevention Program
- SWQPPP** Source Water Quality Protection Partnership Petitions
- SWTR** Surface Water Treatment Rule, as defined in CWA
- SYSOP** Systems Operator
- T**
- TAD** Technical Assistance Document
- TAG** Technical Assistance Grant
- TAL** Target Analyte List
- TALMS** Tunable Atomic Line Molecular Spectroscopy, a laboratory analytical instrument
- TAMS** Toxic Air Monitoring System
- TAMTAC** Toxic Air Monitoring System Advisory Committee
- TAP** Technical Assistance Program
- TAPDS** Toxic Air Pollutant Data System
- TBC** To Be Considered a potential cleanup standard or goal, as defined in CERCLA
- TBT** Tributyltin, a wood preservative
- TC** Target Concentration or Toxicity Characteristics or Toxic Concentration
- TCF** Total Chlorine Free
- TCLP** Total Concentrate Leachate Procedure or Toxicity Characteristic Leachate Procedure, a procedure to assess the leachability of contaminants from soil or solid waste
- TCRI** Toxic Chemical Release Inventory, as defined in SARA
- TD** Toxic Dose
- TDS** Total Dissolved Solids, an indicator of water quality
- TEAM** Total Exposure Assessment Model
- TEC** Technical Evaluation Committee
- TED** Turtle Excluder Devices
- TEGD** Technical Enforcement Guidance Document
- TEL** Tetraethyl Lead
- TEP** Typical End-use Product or Technical Evaluation Panel
- TERA** TSCA Environmental Release Application
- TES** Technical Enforcement Support
- TGAI** Technical Grade of the Active Ingredient
- TGO** Total Gross Output
- TGP** Technical Grade Product
- THC** Total Hydrocarbons
- THM** Trihalomethane
- TIC** Tentatively Identified Compounds
- TIM** Technical Information Manager
- TIP** Technical Information Package
- TIP** Transportation Improvement Program
- TISE** Take It Somewhere Else, a common term used by opponents of a proposed disposal action
- TITC** Toxic Substance Control Act Interagency Testing Committee
- TKN** Total Kjeldahl Nitrogen
- TLV** Threshold Limit Value
- TMDL** Total Maximum Daily Limit or Total Maximum Daily Load, as defined in CWA
- TME** Test Marketing Exemption, as defined by TSCA
- TMRC** Theoretical Maximum Residue Contribution
- TNCWS** Transient Non-Community Water System
- TOA** Trace Organic Analysis
- TOB** Top of Bedrock

**TOC** Total Organic Carbon/Compound  
**TP** Total Particulates  
**TPH** Total Petroleum Hydrocarbons  
**TPQ** Threshold Planning Quantity, as defined by SARA  
**TPSIS** Transportation Planning Support Information System  
**TPY** Tons per Year  
**TQM** Total Quality Management  
**TRC** Technical Review Committee  
**TRD** Technical Review Document  
**TRI** Toxic Release Inventory  
**TRIP** Toxic Release Inventory Program  
**TRIS** Toxic Chemical Release Inventory System  
**TSCA** Toxic Substances Control Act  
**TSCC** Toxic Substances Coordinating Committee  
**TSDF** Technical Support Document; also Treatment, Storage, and Disposal  
**TSDF** Treatment, Storage, and Disposal Facility, as defined in RCRA  
**TSI** Thermal System Insulation  
**TSM** Transportation System Management  
**TSP** Total Suspended Particulates  
**TSS** Total Suspended (nonfilterable) Solids  
**TTO** Total Toxic Organics  
**TTHM** Total Trihalomethane  
**TVOC** Total Volatile Organic Compounds  
**TWA** Time Weighted Average, as defined by OSHA  
**TWS** Transient Water System, as defined by SDWA

## U

**UAC** User Advisory Committee  
**UAM** Urban Airshed Model  
**UAO** Unilateral Administrative Order  
**UAPSP** Utility Acid Precipitation Study Program  
**UAQI** Uniform Air Quality Index  
**UARG** Utility Air Regulatory Group  
**UCC** Ultra Clean Coal  
**UCL** Upper Control Limit, a laboratory instrument performance standard  
**UEL** Upper Explosive Limit  
**UF** Uncertainty Factor, a term used in risk assessment  
**UFFI** Urea-Formaldehyde Foam Insulation  
**UFL** Upper Flammability Limit  
**UGT** Underground Tank  
**UIC** Underground Injection Control, as defined by SDWA and RCRA  
**UM** Uniform Manifest, as defined by RCRA  
**UMTRCA** Uranium Mill Tailings Radiation Control Act  
**USC** Unified Soil Classification, a system used to describe soil features; also United States Code  
**USDA** United States Department of Agriculture

**USDW** Underground Sources of Drinking Water  
**UNECE** United Nations Economic Commission for Europe  
**UNEP** United Nations Environmental Programme  
**USEPA** United States Environmental Protection Agency  
**USFS** United States Forest Service  
**UST** underground storage tank  
**UTM** Universal Transverse Mercator, a grid coordinate system for maps  
**UTP** Urban Transportation Planning  
**UV** Ultraviolet  
**UVA, UVB, UVC** Ultraviolet Radiation Bands  
**UXO** Unexploded Ordnance  
**UZM** Unsaturated Zone Monitoring

## V

**VCP** Voluntary Cleanup Program  
**VE** Visual Emissions  
**VEO** Visible Emission Observation  
**VHAP** Volatile Hazardous Air Pollutant  
**VP** Vapor Pressure  
**VRP** Visibility Reducing Particles  
**VSD** Virtually Safe Dose  
**VSI** Visual Site Inspection  
**VSS** Volatile Suspended Solids

## W

**WA** Work Assignment  
**WADTF** Western Atmospheric Deposition Task Force  
**WAP** Waste Analysis Plan  
**WAVE** Water Alliances for Environmental Efficiency  
**WB** Wet Bulb, used in the measure of humidity  
**WCED** World Commission on Environment and Development  
**WDR** Waste Discharge Requirements  
**WENDB** Water Enforcement National Data Base  
**WERL** Water Engineering Research Laboratory  
**WET** Whole Effluent Toxicity, test  
**WHO** World Health Organization  
**WHPA** Wellhead Protection Area  
**WHPP** Wellhead Protection Program  
**WHWT** Water and Hazardous Waste Team  
**WICEM** World Industry Conference on Environmental Management  
**WL** Working Level, a radon measurement  
**WLA/TMDL** Wasteload Allocation/Total Maximum Daily Load, as defined in CWA  
**WMO** World Meteorological Organization  
**WPCF** Water Pollution Control Federation  
**WQA** Water Quality Act of 1987  
**WQS** Water Quality Standard

**WRC** Water Resources Council  
**WRDA** Water Resources Development Act  
**WRI** World Resources Institute  
**WSF** Water Soluble Fraction  
**WSRA** Wild and Scenic Rivers Act  
**WSTB** Water Sciences and Technology Board  
**WSTP** Wastewater Sewage Treatment Plant

**WWEMA** Waste and Wastewater Equipment  
Manufacturers Association  
**WWTP** Wastewater Treatment Plant

## X

**XRD** X-ray diffraction analysis  
**XRF** X-ray fluorescence analysis



# APPENDIX II

## CHRONOLOGY OF POLLUTION EVENTS

- 1783** *Laki, Iceland.* Laki volcanic eruption releases fluorine in such abundance that it poisons the vegetation, which in turn kills most of the livestock and 25 percent of the human population on Iceland
- 1815** *Tambora, near Java, Indonesia.* Tambora volcano releases such abundance of aerosols into the atmosphere that they cause global cooling and the “year without a summer” in 1816
- 1872** *Yellowstone, Wyoming.* Yellowstone National Park is established by an act of U.S. Congress
- 1890** **September 30.** *Yosemite, California.* Yosemite made a national park by an act of U.S. Congress
- 1892** **May 28.** John Muir establishes Sierra Club in San Francisco, California—the first environmental action organization in the United States
- 1899** U.S. Congress passes the Refuse Act, thereby allowing no refuse into United States marine waters
- 1906** *Witten, England.* Roburite factory chemical explosion
- 1908** **June 30.** *Tunguska, Siberia, Russia.* Comet or asteroid explodes above an uninhabited area of Siberia, flattening forests and killing all animals for 20 miles (32 km)
- 1910** Ringelmann’s Smoke Opacity Scale developed to rate thickness of smoke
- 1916** National Park Service established by an act of U.S. Congress
- 1918** *Newark, New Jersey.* Butterworth & Judson Chemical Works explosion  
*Oakdale, Pennsylvania.* Aetna Chemical Co. explosion
- 1919** **January 15.** *Boston, Massachusetts.* The great Boston Molasses Disaster
- 1930** **December 1–5.** *Meuse, Belgium.* Meuse Valley air pollution disaster from a temperature inversion trapping sulfur dioxide
- 1934–1940** *Southern Great Plains, United States.* Dust bowl drought and dust storms
- 1938** U.S. Congress enacts the Federal Food, Drug, and Cosmetic Act
- 1940–1960** *Minamata, Japan.* Chisso chemical plant produces severe mercury contamination and public health crisis
- 1944** *Los Angeles, California.* Los Angeles Bureau of Air Pollution Control established to combat rampant air pollution
- 1945** *Los Alamos, New Mexico.* Detonation of the first atomic devices  
*Hiroshima and Nagasaki, Japan.* Dropping of first uranium- and plutonium-based atomic bombs in warfare. Numerous humans exposed to severe radiation
- 1946–1958** *Bikini and Eniwetok Atolls.* Atomic and hydrogen bomb testing by the United States military
- 1947** *Los Angeles, California.* Los Angeles Air Pollution Control District established to battle air pollution with legal capability  
Federal Insecticide, Fumicide, and Rotenticide Act (FIFRA) signed into law
- 1948** **April 16.** *Texas City, Texas.* Explosion of 2,300 tons (2,030 metric tons) of ammonium nitrate causes a chain reaction killing 581 people, the deadliest industrial disaster in U.S. history.  
Nobel Prize awarded to Paul Muller for discovery that DDT could be used as a potent pesticide  
**October 26–30.** *Donora, Pennsylvania.* Donora air pollution disaster from industrial emissions from a zinc and steel plant during a temperature inversion

- 1949** *New York City, New York.* New York City Smoke Control Board established to address air pollution issues
- 1950** **November 24. Poza Rica, Mexico.** Poza Rica air pollution disaster of hydrogen sulfide gas from an oil refinery
- 1951** Rachel Carson publishes *The Sea around Us*
- 1952** **December 5–9. London, England.** “Killer Fog” strikes London from a temperature inversion killing upward of 12,000 people. Probably the worst strictly environmental disaster ever
- 1954** International Convention for the Prevention of Pollution of the Sea by Oil convened and regulations established
- 1955** *Pennsylvania, United States.* Pennsylvania passes the first air pollution law in the United States, primarily as the result of the Donora disaster  
Air Pollution Control Act (APCA) of 1955 signed into law as the first nationwide pollution legislation
- 1956** Clean Air Act of 1956 enacted in Great Britain largely as the result of the 1952 Killer Fog disaster
- 1957** The term *greenhouse effect* named and defined by Roger Revelle and Hans Suess
- 1959** Cranberries banned for Thanksgiving in the United States because of pesticide scare
- 1960** *California, United States.* California Motor Vehicle Pollution Control Act
- 1961** *Idaho Falls, Idaho.* Nuclear reactor explosion
- 1961–1970** *South Vietnam.* United States military forces use Agent Orange as a defoliant
- 1962** Rachel Carson publishes the American environmental landmark book *Silent Spring*.  
*London, England.* Pollution fog strikes again  
**May. Centralia, Pennsylvania.** Pennsylvania coal mine fires begin
- 1963** Clean Air Act of 1963 enacted by the U.S. Congress  
**January 29–February 13. New York City, New York.** New York City air pollution disaster
- 1964** **April 14.** Rachel Carson dies of breast cancer
- 1965** Clean Air Act of 1963 amended by the U.S. Congress  
Solid Waste Disposal Act (SWDA) enacted by the U.S. Congress
- 1966** Clean Air Act of 1963 amended by U.S. Congress again through pressure by environmentalists
- 1967** Clean Air Act of 1963 amended again  
**March 18. Cornwall, England.** *Torrey Canyon* oil spill in the Scilly Islands, the United Kingdom. The first major oil spill from a supertanker  
*Saudi Arabia.* Endrin poisoning of bread kills 26 and hospitalizes 874  
Air Quality Act of 1967 enacted by U.S. Congress
- 1968** United Nations Conference on the Human Environment
- 1969** Clean Air Act of 1963 amended by U.S. Congress  
Civil Liability Convention—Supertanker insurance and liability established for oil spills primarily in response to the *Torrey Canyon* disaster  
*Vancouver, Canada.* Greenpeace environmental advocacy organization established  
**January 29. Santa Barbara Channel, California.** Oil platform blowout and spill capture the attention of the American public and spur the environmental movement  
**June 22. Cleveland, Ohio.** Cuyahoga River fire, not very impressive but well covered by the media because of the interest in the environment generated by the Santa Barbara oil spill
- 1970** Clean Air Act of 1970 with sweeping changes in air quality legislation enacted by U.S. Congress  
Air Pollution Control Act of 1970 enacted by U.S. Congress  
*Port Hawkesbury, Nova Scotia, Canada.* *Arrow* tanker oil spill  
*Bangladesh.* Flood, water pollution, and disease resulting from the devastating cyclone and natural disaster of the century  
*St. Petersburg, Florida.* *Delian Apollon* tanker oil spill  
**January 1.** National Environmental Policy Act enacted by U.S. Congress  
**April 22.** First Earth Day in America attended by huge crowds in cities across the country galvanizes the environmental movement  
**December 2.** The U.S. Environmental Protection Agency founded by act of U.S. Congress  
*Monticello, Minnesota.* Nuclear reactor explosion

- International Oil Compensation Fund established to pay for oil spills
- 1972** DDT banned in the United States, fulfilling Rachel Carson's legacy  
*Glen Avon, California.* Stringfellow Quarry pollution—one of the major polluted sites in the country with no funds to remediate it  
 Marine Protection, Research, and Sanctuaries Act enacted by U.S. Congress to combat marine pollution  
 United Nations Conference on the Human Environment, first worldwide conference to address global environmental problems  
 Modernized version of the Federal Insecticide, Fumicide, and Rodenticide Act (FIFRA) to address pollution and public health issues  
**July 22. Portland, Maine.** *Tamano* tanker oil spill and cleanup
- 1972–1974** NIOSH National Occupational Hazard Survey undertaken to determine exposure of workers to hazardous substances in the workplace
- 1973** International Convention for the Prevention of Pollution (MARPOL) agreement among a group of nations to reduce marine (MAR) pollution (POL). This is the first MARPOL agreement  
 Benzidine banned in the United States for reasons of public health  
**December.** The initiation of the EPA-directed phased reduction of lead from all substances beginning with gasoline
- 1974** Safe Drinking Water Act enacted by U.S. Congress as a comprehensive program to safeguard water supplies. It is still in effect today
- 1975** *London, England.* United Nations Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter
- 1976** Chloroform banned from general usage in the United States  
 Resource Conservation and Recovery Act (RCRA) to regulate the disposal of solid waste passed by U.S. Congress into law  
 Toxic Substances Control Act passed by U.S. Congress specifically to address the removal of PCBs  
 Federal Food, Drug, and Cosmetic Act amended and modernized to address issues of chemical residues and exposure to hazardous substances
- May 12. La Coruña, Spain.** *Urquiola* supertanker oil spill
- July 10. Meda, Italy.** Seveso dioxin release—air pollution/industrial disaster
- December 15. New England, United States.** *Argo Merchant* supertanker accident and oil spill
- 1977** U.S. Congress declares national parks to be class I attainment zones for air pollution  
 DBCP pesticide banned from use in the United States  
 Lindane pesticide banned from use in the United States  
**February 25. Hawaii, United States.** *Hawaiian Patriot* tanker accident and oil spill
- April 22. North Sea.** Ekofisk oil well blowout and oil spill
- 1978** International Convention for the Prevention of Pollution (MARPOL) agreed upon by an international contingent. The second marine (MAR) pollution (POL) accord includes more stringent restrictions to cover some shortcomings of MARPOL 1973  
 Freon (CFC) 11 banned in the United States
- March 16. Ouessant, France.** *Amoco Cadiz* tanker accident and oil spill
- August 7. Niagara Falls, New York.** Love Canal pollution disaster declared a federal emergency by President Carter. This is the first time that this designation is used for anything other than a natural disaster. Probably the most extensively polluted site in the world. Revives the environmental movement
- 1979** Greenpeace International established. Shows the rapid growth of concern for environmental issues on a global basis  
**March 28. Middletown, Pennsylvania.** Three Mile Island nuclear power plant accident results in no deaths or damage to public health but heightens fears of the American public about the dangers of nuclear power
- June 3. Mexican Gulf of Mexico.** Ixtoc I blowout and oil spill, by far the largest oil spill in history up to that time and the third largest ever
- July 19. Tobago.** *Atlantic Empress* tanker accident and oil spill
- November 1. Houston, Texas, United States.** *Burmah Agate* tanker accident and oil spill

- 1979–1983 Bangladesh.** Drilled shallow-tube water well program initiated by the United Nations. The goal is to eliminate the rampant disease of surface water use but results in massive arsenic poisoning because it occurs naturally in the shallow aquifer in much of the country. Problem continues today
- 1980** TCE (trichloroethylene) restricted in the United States by EPA  
**Brooks, Kentucky.** Valley of the Drums future Superfund site established. Nearly as infamous as Love Canal, this pollution disaster also captures the attention of the American public  
 Low Level Radioactive Waste Policy Act of 1980 ratified by U.S. Congress and signed into law  
**April 21. Elizabeth, New Jersey.** Chemical Control Corp. fire and explosion of a profoundly polluted site also captures the attention of the American public  
**December 11.** Comprehensive Environmental Response Compensation and Liability Act (CERCLA) is signed into law by the president. It establishes the National Priorities List and Superfund largely as the result of the infamy of profoundly polluted sites such as Love Canal, Valley of the Drums, Times Beach, and Stringfellow. Provides public funds to clean up such sites and legal authority to pursue polluters
- 1981** EPA-directed removal of lead from foods  
**Oswego, New York.** Pollution Abatement Services Superfund site established and pollution addressed  
**October. New Jersey.** Price's Pit Superfund site established and addressed
- 1981–1983** NIOSH National Occupational Exposure Survey second and more comprehensive program undertaken to determine exposure of workers to hazardous substances in the workplace
- 1982** **Times Beach, Missouri.** Dioxin contamination and Superfund site declared. The most extreme measures ever taken in a cleanup; the whole town is evacuated, destroyed, and incinerated  
 Toxaphene pesticide banned from use in the United States
- 1983** **Shoshone County, Idaho.** Bunker Hill Complex Superfund Site established  
**Glen Avon, California.** Stringfellow Quarry finally declared a Superfund site; gained national attention years earlier for profound pollution
- February 4. Persian Gulf.** *Norwuz* blow-out and oil spill. One of several from the Iran-Iraq War, but this is the most significant by far
- August 6. Cape of Good Hope, South Africa.** *Castillo de Bellver* tanker accident and oil spill
- September 8. Woburn, Massachusetts.** Woburn Superfund site is established. Later achieves fame as the centerpiece of the movie *A Civil Action*
- 1984** **Minnesota, the United States.** Bell Lumber & Pole Superfund established  
 EDB (1,2-dibromoethane) pesticide an industrial chemical banned for use in the United States  
 RCRA Hazardous and Solid Waste Amendments enacted by U.S. Congress to address major shortcomings of the 1976 act
- September 21. Corvallis, Oregon.** United Chrome Superfund site is established
- December 3. Bhopal, India.** Union Carbide pesticide plant explosion is possibly the worst industrial accident ever in history. More than 3,500 killed
- 1985–2002** U.S. Geological Survey National Water Quality Assessment Program evaluates the contaminants and their concentrations in public water supplies across the United States to determine exposure
- 1986** Safe Drinking Water Act amended by U.S. Congress to address shortcomings of the original act  
**April 26. Pripyat, Ukraine.** Chernobyl nuclear power plant explosion and leak. The worst nuclear accident in history exposes most of northern Europe to dangerous levels of radiation
- August 21. Lake Nyos, Cameroon.** Volcanic gas cloud unexpectedly released from the bottom waters of the lake and asphyxiates an entire village, killing 1,700 people
- October 17.** Superfund Amendments and Reauthorization Act (SARA) enacted by U.S. Congress and signed into law. This act continues the Superfund program and expands its capacity and authority  
 Pesticides aldrin and dieldrin banned from use in the United States
- 1987** **Hill Air Force Base, Utah, United States.** Hill Air Force Base placed on Superfund list



- Montreal, Quebec, Canada.* Montreal Protocol developed. United Nations sponsors a convention to address the destruction of the stratospheric ozone layer by CFCs. Widely approved and enacted
- Colorado, United States.* Rocky Mountain Arsenal declared a Superfund site
- Marine Plastic Pollution and Control Act* approved by the U.S. Congress and signed into law
- 1987–1993** EPA Toxic Release Survey conducted to determine the amount of industrial release of pollutants to the environment in the United States
- 1987–1997** *Hinkley, California.* Pacific Gas & Electric pollution uncovered. Resulting lawsuit becomes the topic of the movie *Erin Brockovitch*
- 1988** *St.-Basile-le-Grand, Canada.* Toxic cloud develops from toxic waste dump
- Heptachlor pesticide banned for use in the United States
- Lead Contamination Control Act signed into legislation. Designed to remove all remaining common uses of lead
- Sofia, Bulgaria.* Sofia Protocol developed. United Nations sponsors a conference to reduce nitrogen oxides from the air on a global basis
- Ocean Dumping Ban Act and Public Vessel Medical Waste Anti-Dumping Act enacted largely to address arising issues of waste washing onto beaches
- April 14.** Pesticide chlordane banned in the United States. It was one of the last of the pesticides identified in the book *Silent Spring* to be banned
- 1989** *Anniston, Alabama.* Anniston Army Depot declared a Superfund site
- Earth in Balance* book, published by Al Gore. This is the future vice president's first book on the environment
- Ohio, United States.* Feed Materials Production Center declared a Superfund site
- Methylene chloride banned in hairspray in the United States
- The industrial chemical TCE (trichloroethylene) banned in the United States
- March 24.** *Valdez, Alaska.* Exxon Valdez supertanker grounding and oil spill in Prince George's Sound. Largest oil spill in the United States until 2010
- 1990** Clean Air Act of 1970 revised and expanded by U.S. Congress to attain current standards. Numerous jurisdictions are still in nonattainment with the new stringent regulations
- National Ambient Air Quality Standards (NAAQS) established for the United States
- Oil Pollution Control Act signed into law to control oil spills from tankers better. Largely enacted in response to the *Exxon Valdez* disaster
- Radiation Exposure Compensation Act signed into law. This bill is designed to compensate residents near nuclear test sites for health problems related to nuclear fallout
- Roger Revelle receives National Medal of Science for being the "grandfather of the greenhouse effect and global warming"
- 1991** *Oil fields, Kuwait.* Oil field fires and contamination purposefully started by retreating Iraqis during and after the Gulf War (Desert Storm). This is the largest environmental release of oil ever
- The pesticide endrin is banned in the United States
- Phenylmercuric acid banned from use in latex paints in the United States
- Philippines.* Mt. Pinatubo erupts, sending large amounts of sulfur into the atmosphere, which act as aerosols dispersing sunlight for the next year and contributing to air pollution
- 1992** International Oil Compensation Fund established by an international conference to help pay for oil spill damage and cleanup
- A U.S. congressional panel names Rachel Carson's *Silent Spring* "the most influential book of the last 50 years"
- Nuclear Test Ban Treaty ratified
- Rocky Mountain Arsenal Wildlife Refuge Act signed into legislation by the U.S. Congress to restore the area to natural conditions
- December 13.** *Galicia, Spain.* Aegean Sea supertanker accident and oil spill
- 1993** *Bartlesville, Oklahoma.* National Zinc designated a Superfund site
- January 5.** *Scotland, United Kingdom.* Braer supertanker accident and oil spill
- 1994** *Usnisk, Russia.* Oil spill from a broken pipeline in the Arctic
- Wetlands Act signed into legislation to preserve wetlands in the United States
- California Desert Protection Act enacted by U.S. Congress to prevent further environmental degradation of the fragile desert ecology

- 1995** EPA brownfields redevelopment program, officially known as the Small Business Liability & Brownfield Revitalization Act, signed into law. This legislation makes it possible for profoundly polluted sites that would never achieve “greenfield” status to be partly remediated and restored to useful service  
Paul Crutzen, Mario Molina, and Sherwood Rowland collaboratively receive the Nobel Prize in chemistry for their work documenting destruction of the stratospheric ozone layer primarily by CFCs  
**December 31.** Lead banned for use in gasoline. Although it had been eliminated in most commercially available vehicles long before this, the last minor uses are finally eliminated as well
- 1996** The industrial chemical and VOC TCA-(1,1,1-trichloroethane) is banned  
Safe Drinking Water Act amended by U.S. Congress to achieve the current rigorous standards. It is the current version
- 1997** Annex VI of the MARPOL agreement is enacted to control diesel exhaust in the marine environment  
**December 11.** *Kyoto, Japan.* Kyoto Protocol is drafted and adopted in a United Nations conference to reduce greenhouse gases. Several countries have yet to sign, including the United States
- 1998** Louisiana-Pacific Corp. loses largest air pollution violation case in Clean Air Act history
- 1999** **March.** *New Mexico, United States.* Waste Isolation Pilot Plant (WIPP) established as a national repository for transuranic waste  
**December 12.** *Brittany, France.* Erika supertanker accident and oil spill
- 2001** **September 11.** *New York City, New York.* World Trade Center disaster is caused by terrorists flying commercial airliners into both towers of the World Trade Center and destroying them. The act kills nearly 3,000 American citizens and creates a toxic cloud that still affects exposed rescue, relief, and cleanup workers
- 2002** The United States ends domestic production of asbestos  
**February 22.** The United States enacts the Arsenic Rule, which limits arsenic to 10 parts per billion in water  
**November 13–19.** *Galicia, Spain.* Prestige supertanker accident and oil spill
- 2003** **July 27.** *Port Karachi, Pakistan.* Tasman Spirit supertanker accident and oil spill
- 2004** The industrial chemical Diazinon is heavily restricted in the United States  
**November.** The Regional Greenhouse Gas Initiative is adopted by nine northeastern states (Maine, Massachusetts, New Hampshire, Vermont, Rhode Island, Connecticut, New York, New Jersey, and Delaware) to reduce greenhouse gas production under the terms of the Kyoto Protocol
- 2005** Cap and trade plan for mercury emission from older coal-burning power plants adopted by the George W. Bush administration. Creates significant loopholes for the most polluting power plants, which otherwise would have had to be shut down or refitted  
The Energy Policy Act of 2005 is enacted. It calls for a stepped phaseout of MTBE  
**March 23.** *Texas City, Texas, the United States.* Explosion and fire at a BP oil refinery kills 15 and injures 170 people  
**August 29.** *New Orleans, Louisiana.* Hurricane Katrina destroys the American city killing more than 1,400 residents and creating a “toxic soup” of pollutants and waste in the flooding salt water  
**November 13.** *Harbin, China.* A chemical factory spills 100 tons (90 metric tons) of benzene into the Songhau River, killing five people and causing an international incident with Russia
- 2006** *An Inconvenient Truth* published by former vice president Al Gore about the dangers of greenhouse gases and global warming. A documentary of the same name is also produced
- 2007** CO<sub>2</sub> is declared a pollutant that could be regulated by the EPA  
The documentary *An Inconvenient Truth* by Al Gore wins two Academy Awards  
Al Gore receives the Nobel Prize in peace for his work on raising the public awareness of the problems of global warming and greenhouse gases  
*Nye County, Nevada.* Scheduled date for the opening of the Yucca Mountains high-level nuclear waste repository
- 2008** *Sichuan, China.* Massive earthquake (M-8) strikes Sichuan, China, and causes major environmental damage  
**December 22.** *Kingston, Tennessee.* Large release of coal ash into the Tennessee River.

- 2009** *Copenhagen, Denmark.* UN Copenhagen Accord signed to supersede Kyoto Protocol. Designed to reduce CO<sub>2</sub> emissions by 2020
- 2010** **January 12.** *Port-au-Prince, Haiti.* Massive earthquake (M-7.2) strikes Haiti, leaving 200,000 people dead and causing major environmental damage  
**April 15–20.** Emissions of ash from volcano Eyjafjallajökull close airports across Europe  
**April 20.** *Louisiana, Gulf of Mexico, United States.* Explosion and fire on the Deepwater Horizon drilling platform releases an estimated 204 million gallons (772.2 million L) of oil into the Gulf of Mexico over the next three months. Declared the worst environmental disaster in U.S. history  
**October 5.** *Kolontar, Hungary.* Chemical spill from aluminum plant kills seven and injures 150 people.  
**December.** *Ringwood, New Jersey.* Ford Motor Company ordered by EPA to return to the Superfund site it created to remove thousands of tons of additional toxic paint sludge
- 2011** **January.** *Spelter, West Virginia.* DuPont pays \$70 million to clean up a zinc smelter and 100-foot (30-m) tailings pile and fund long-term medical monitoring of residents
- March 11.** *Honshu, Japan.* A magnitude 9.0 earthquake and resulting tsunami strike northeastern Japan, killing more than 20,000 people and damaging four nuclear power plants. The Fukushima plant released radiation and was the second-worst civilian nuclear accident ever
- March 16.** *Tristan da Cunha Islands.* Tanker MS *Olivia* spills 800 tons (726 metric tons) of fuel oil into ecologically sensitive area of southernmost Atlantic Ocean
- April 25–29.** *Geneva, Switzerland.* Pesticide endosulfan is officially banned on a worldwide basis by international agreement by the Stockholm Convention of the Review Committee on Persistent Organic Pollutants
- April 27.** *Southern United States.* One of the worst outbreaks of tornadoes in history kills more than 300 people and causes extensive pollution problems
- Nye County, Nevada.** Scheduled date for the opening of the Yucca Mountains high-level nuclear waste repository, if it is not scuttled by congressional debates in 2010–11

2017

# APPENDIX III

## GLOSSARY

**abandoned well** a well whose use has been permanently discontinued or is in a state of such disrepair that it cannot be used for its intended purpose. The closure of wells is regulated by local agencies. For oil wells, the top 50 feet (15.4 m) must be pumped full of cement

**abatement** reducing the degree or intensity of, or eliminating, pollution of water, soil, air, or structures

**abiotic** any nonliving component of the environment

**absorbed dose** in an exposure assessment, the amount of a substance that penetrates an exposed organism's defensive mechanisms such as skin, lung tissue, or gastrointestinal tract through physical or biological processes. Synonymous with *internal dose*

**absorption** the uptake of water, other fluids, or dissolved chemicals by a cell or an organism

**absorption barrier** the parts of an organism that retard the penetration, uptake, or exchange of various substances (e.g., skin, lung tissue, and gastrointestinal tract wall)

**abyssal plain** a flat, level, mostly featureless part of the ocean floor present between the midoceanic ridge and the continental rise

**acclimatization** the physiological and behavioral adjustments made by an organism to changes in its environment

**accuracy** a measurement in which the determined quantity is exactly correct for the individual determination whether it can be repeated or not. See PRECISION

**acid** a corrosive and dissolving solution with a pH less than 7. The lower the pH, the stronger the acid will be

**acid deposition** a complex chemical and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the

original sources, and then deposited on Earth in either wet or dry form. The wet forms, popularly called acid rain, can fall to earth as rain, snow, or fog. The dry forms are acidic gases or particulates

**acid neutralizing capacity** measure of the ability of a base (e.g., water or soil) to resist a decrease in pH if mixed with a solution or solid

**acid rain** See ACID DEPOSITION

**action levels** concentrations of pesticides recommended by U.S. Environmental Protection Agency for enforcement by the Food and Drug Administration and the U.S. Department of Agriculture if residues are present in food or animal feed as a result of other than the direct application of the pesticide (see TOLERANCES). Also, in the Superfund program, the existence of a contaminant concentration in the environment at levels sufficient to warrant enforcement action or trigger a response under SARA or the NCP

**activated carbon** a highly adsorbent form of carbon utilized to remove odors and toxic substances from liquid or gaseous emissions. It is commonly used to adsorb (filter out or capture) dissolved organic matter from drinking water as granulated activated carbon (GAC)

**activator** a chemical added to a pesticide to increase its effectiveness

**active ingredient** in any pesticide product, the active ingredient is the chemical compound that does the actual killing or otherwise controls, target pests. Pesticides are regulated primarily on the basis of active ingredients

**acute effect** an adverse effect on any living organism that results from a single significant dose of a chemical compound. These severe symptoms tend to develop rapidly

**acute exposure** a single exposure to a toxic substance that may result in severe biological harm (illness) or death. Acute exposures are usually characterized as lasting no longer than a day, as



compared to longer, continuing exposure over time. See CHRONIC EXPOSURE

**acute toxicity** the ability of a substance to cause severe biological harm or death soon after a single exposure or dose. Also used to describe any poisonous effect resulting from a single short-term exposure to a toxic substance. See TOXICITY

**adaptation** changes in an organism's physiological structure or function or habits that allow it to survive in new surroundings

**add-on control device** an air pollution control device such as carbon absorber or incinerator that reduces the pollution in an exhaust gas. The added control device usually does not affect the process being controlled

**adhesive forces** the attractions that molecules of one substance exert on those of a different substance

**administered dose** in exposure assessment, the amount of a substance given to a test subject (human or animal) to determine dose-response relationships. Since exposure to chemicals is usually inadvertent, this quantity is often called potential dose

**Administrative Order** a legal document signed by the U.S. Environmental Protection Agency directing an individual, business, or other entity to take corrective action or refrain from an activity. It describes the violations and actions to be implemented and can be enforced in court

**Administrative Order on Consent** a legal agreement signed by the U.S. Environmental Protection Agency and an individual, business, or other entity through which the violator agrees to pay for correction of violations, take the required corrective or cleanup actions, or refrain from an activity. It describes the actions to be taken, may be subject to a comment period, applies to civil actions, and can be enforced in court

**Administrative Procedures Act** a law that explicitly defines the procedures and requirements related to the promulgation of regulations

**Administrative Record** all documents that the U.S. Environmental Protection Agency considered or relied on in selecting the response action at a Superfund site, culminating in the record of decision (ROD) for remedial action or an action memorandum for removal of pollution and polluted materials

**adsorption** removal of a pollutant from air or water by collecting the pollutant on the surface of a solid material. For example, activated carbon removes (adsorbs) organic matter from wastewater

**adulterants** chemical impurities or substances that by law do not belong in a food or pesticide

**advanced treatment** a level of wastewater treatment more stringent than secondary treatment. It requires an 85 percent reduction in conventional pollutant concentration or a significant reduction in nonconventional pollutants concentration. See TERTIARY TREATMENT

**advanced wastewater treatment** any treatment of sewage that goes beyond the secondary or biological water treatment stage and includes the removal of nutrients such as phosphorus and nitrogen and a high percentage of suspended solids. See PRIMARY TREATMENT; SECONDARY TREATMENT

**advection** the horizontal component of a convection current in air (e.g., wind)

**advisory** a nonregulatory document that communicates risk information to those who may have to make risk management decisions (e.g., fish consumption advisory)

**aerated lagoon** a holding and/or treatment pond that speeds up the natural process of biological decomposition of organic waste by stimulating the growth and activity of aerobic bacteria that degrade organic waste through the rapid infusion of air into the wastewater

**aeration** a process that promotes biological degradation of organic matter in water. The process may be passive (as when waste is exposed to air) or active (as when a mixing or bubbling device introduces the air)

**aerobic** life or processes that require, or are not destroyed by, the presence of oxygen. See ANAEROBIC

**aerobic treatment** process by which microbes decompose complex organic compounds in the presence of oxygen and use the liberated energy for reproduction and growth. Such processes take place in aeration tanks, trickling filtration systems, and rotating biological contactors

**aerosol** small droplets or particles suspended in the atmosphere that can reflect and disperse incoming solar radiation. They are usually emitted naturally (in volcanic eruptions) and as the result of anthropogenic (human) activities such as burning fossil fuels. *Aerosol* is also a term used to describe the pressurized gas used to propel substances out of a container

**affected public** the people who live and/or work near a hazardous waste site. Also, the human population adversely impacted after exposure to a toxic pollutant in food, water, air, or soil

**afterburner** an air pollution control device on an incinerator in which the combustion gases

are made to pass through its flame in order to remove smoke and odors

**agent** any physical, chemical, or biological entity that can be harmful to an organism. Also called stressor

**Agent Orange** a toxic herbicide and defoliant used in the Vietnam conflict, containing 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and 2,4-dichlorophenoxyacetic acid (2,4-D) with trace amounts of dioxin

**agricultural pollution** farming wastes, including runoff and leaching of pesticides and fertilizers; erosion and dust from plowing; improper disposal of animal manure and carcasses; crop residues; and debris

**agricultural waste** poultry and livestock manure and residual materials in liquid or solid form generated from the production and marketing of poultry, livestock, or fur-bearing animals; also includes grain, vegetable, and fruit harvest residue

**agroecosystem** land used for crops, pasture, and livestock; the adjacent uncultivated land that supports other vegetation and wildlife; and the associated atmosphere, underlying soils, groundwater, and drainage networks

**airborne particulates** total suspended particulate matter found in the atmosphere as solid particles or liquid droplets. Chemical composition of particulates varies widely, depending on location and time of year. Sources of airborne particulates include dust, emissions from industrial processes, combustion products from the burning of wood and coal, combustion products associated with motor vehicle or nonroad engine exhausts, and reactions to gases in the atmosphere

**airborne release** release of any pollutant into the air

**air contaminant** any individual or combination of particulate matter or gas other than water vapor present in the atmosphere. See AIR POLLUTANT

**air curtain** a method of containing oil spills. Air bubbling through a perforated pipe causes an upward water flow that slows the spread of oil. It can also be used to stop fish from entering polluted water

**air mass** a large volume of air in the atmosphere with certain meteorological or pollution characteristics (e.g., smog, particulate) that reflect its location of origin (e.g. Canadian air mass, Gulf of Mexico air mass). The characteristics can change as the air mass moves away

**air permeability** permeability of soil with respect to air. It is important to the design of soil-gas

surveys. Measured in darcy or centimeter per second

**air plenum** any space used to convey air in a building, furnace, or structure. The space above a suspended ceiling is often used as an air plenum

**air pollutant** any substance in air that could, in high enough concentration, harm people, animals, vegetation, or material. It can be in the form of individual or groups of solid particles, liquid droplets, or gases but excludes pollen, fog, and dust, which are of natural origin. Air pollutants are often grouped in categories for ease in classification: solids, sulfur compounds, volatile organic chemicals, particulate matter, nitrogen compounds, oxygen compounds, halogen compounds, radioactive compound, and odors

**air pollution control device** mechanism or equipment that cleans emissions generated by a pollution source and removes the pollutants that would otherwise be released to the atmosphere

**air pollution episode** a period of abnormally high concentration of air pollutants, often due to low winds and temperature inversion, that can cause illness and death

**Air Quality Criteria** the levels of pollution and lengths of exposure to certain contaminants above which adverse health and welfare effects may occur

**Air Quality Standards** the level of pollutants prescribed by federal or state regulations that is not to be exceeded during a given time in a defined area

**air sparging** injecting air or oxygen into an aquifer to strip or flush volatile contaminants as air bubbles up through the groundwater to be captured by a vapor extraction system

**air stripping** a treatment system that removes volatile organic compounds (VOCs) from contaminated groundwater or surface water by forcing an airstream through the water and causing the compounds to evaporate

**air toxics** any air pollutant for which a National Ambient Air Quality Standard (NAAQS) does not exist (other than ozone, carbon monoxide, PM10, sulfur dioxide, nitrogen oxide) that may reasonably be anticipated to cause cancer; respiratory, cardiovascular, or developmental effects; reproductive dysfunctions; neurological disorders; heritable gene mutations; or other serious or irreversible chronic or acute health effects in humans

**alachlor** a dangerous herbicide, marketed under the trade name Lasso, used mainly to control weeds in corn and soybean fields

**Alar** trade name for daminozide, a pesticide that makes apples redder, firmer, and less likely to drop off trees before growers are ready to pick them. It also is used to a lesser extent on peanuts, tart cherries, Concord grapes, and other fruits

**aldicarb** an insecticide sold under the trade name Temik. It is made from ethyl isocyanate

**algae** simple rootless plants that grow in sunlit waters in proportion to the amount of available nutrients. They can affect water quality adversely by lowering the dissolved oxygen in the water. They are food for fish and small aquatic animals

**algal blooms** sudden quick growth of algal population in an area, which can adversely affect water quality and indicate potentially serious changes in local water chemistry

**algicide** substance or chemical used specifically to kill or control algae

**aliquot** a measured portion of a sample taken for analysis. One or more aliquots make up a sample

**alkaline** the condition of water or soil that contains a sufficient amount of alkali elements and compounds to raise the pH above 7.0

**alkalinity** the capacity of bases to neutralize acids. An example is lime added to lakes to decrease acidity

**allergen** a substance that causes an allergic reaction in individuals sensitive to it

**alloy** a mixture of a metal and one or more additional elements, most commonly additional metals

**alpha particle** a high-energy radioactive particle (two protons and two neutrons) produced by the radioactive decay of certain isotopes

**alternative fuels** substitutes for traditional liquid, oil-derived motor vehicle fuels such as gasoline and diesel. Includes mixtures of alcohol-based fuels with gasoline, methanol, ethanol, compressed natural gas, and others

**ambient air** any unconfined portion of the atmosphere, open air, or surrounding air

**ambient measurement** a measurement of the concentration of a substance or pollutant within the immediate environs of an organism; taken to relate it to the amount of possible exposure

**ambient temperature** temperature of the surrounding air or other medium

**amensalism** relationship between species in which one organism is harmed and the other is unaffected (e.g., large trees shading and preventing or limiting the growth of small trees)

**amphibole** a group of ferromagnesian silicate minerals found in crystalline rocks that includes certain forms of asbestos (crocidolite and tremolite)

**anaerobic** a life or process that operates in the absence of oxygen

**anaerobic decomposition** degradation or the reduction of the net energy level and change in chemical composition of organic matter caused by microorganisms in an oxygen-free environment

**analyte** a substance whose concentration is being determined, usually through a laboratory test

**animal dander** tiny scales of animal skin, a common indoor air pollutant

**animal studies** investigations using animals as surrogates for humans with the expectation that the results are pertinent to humans

**anion** a negatively charged ion, either a single element or compound by gain of electrons. Reacts with a cation to form a stable compound

**anisotropy** the condition of a material in which the properties are not isotropic in their distribution (e.g., layering). In hydrology, the conditions under which one or more hydraulic properties of an aquifer vary from a given reference point

**annular space, annulus** the open space between two concentric tubes or casings, or between the casing and the borehole wall of a soil-boring or soil-monitoring well

**antagonism** interference or inhibition of the effect of one chemical by the action of another

**antigen** a substance that when introduced into the body stimulates the production of an antibody. Antigens include toxins, bacteria, foreign blood cells, and the cells of transplanted organs

**antimicrobial** an agent that kills microbes

**Applicable or Relevant and Appropriate Requirements (ARARs)** any state or federal statute that pertains to protection of human life and the environment in addressing specific conditions or use of a particular cleanup technology at a Superfund site

**applied dose** in exposure assessment, the amount of a substance in contact with the primary absorption boundaries of an organism (e.g., skin, lung tissue, gastrointestinal tract) and available for absorption

**aquaculture** the raising of aquatic organisms for food in controlled environments (e.g., fish farming)

**aqueous** a solution or other medium that is volumetrically dominated by water

**aqueous solubility** the maximal amount of a chemical (solute) that will dissolve in pure water at a given temperature, pressure, and other constraints

**aquifer test** a test to determine hydraulic properties (yield, flow rate) of an aquifer

**aquitard** geological formation that may contain groundwater but is not capable of transmitting significant (usable) quantities of it under normal hydraulic gradients

**architectural coatings** coverings such as paint and roof tar that are used on exteriors of buildings to protect them from detrimental effects of weather and organisms

**Area of Concern (AOC)** any existing or former location where hazardous substances, hazardous wastes, or pollutants are or were known or suspected to have been discharged, generated, manufactured, refined, transported, stored, handled, treated, or disposed, or where hazardous substances, hazardous wastes, or pollutants have or may have migrated. Areas of concern are targeted for evaluation as part of a site investigation

**aromatics** a type of hydrocarbon, such as benzene or toluene, with a specific type of ring structure. Aromatics are sometimes added to gasoline in order to increase octane. Some aromatics are toxic

**arsenicals** pesticides containing arsenic

**artesian (aquifer or flowing well)** water held under enough pressure in an aquifer confined by impermeable layers that it can flow to the surface if penetrated by a well

**asbestos abatement** procedures to control fiber release from asbestos-containing materials in a building or to remove them entirely, including removal, encapsulation, repair, enclosure, encasement, and operations and maintenance programs

**Asbestos-Containing Waste Materials (ACWM)** mill tailings or any waste that contains commercial asbestos and is generated by a source covered by the Clean Air Act Asbestos NESHAPS

**asbestosis** a disease associated with inhalation of asbestos fibers. The disease makes breathing progressively more difficult and can be fatal

**ash** the chemical product remaining after complete combustion of a substance

**assay** a test for a specific chemical, microbe, or effect as a proportion of an enclosing material

**assimilative capacity** the capacity of a natural body of water to receive wastewaters or toxic materials without deleterious effects and without damage to aquatic life or humans who consume the water

**atmosphere** a mixture of gases, mostly nitrogen and oxygen, with smaller amounts of argon, carbon dioxide, and other gases

**atom** the smallest unit or amount of an element

**atomic mass** the total number of protons and neutrons in an atom; each has 1 atomic mass unit

**atomic number** the number of protons in the nucleus of an atom or electrons in the shells

**attainment area** an area considered to have air quality as good as or better than the National Ambient Air Quality Standards, as defined in the Clean Air Act for individual pollutants. An area may be an attainment area for one pollutant and a nonattainment area for others

**attenuation** the process by which a compound is reduced in concentration over time, through absorption, adsorption, degradation, dilution, and/or transformation

**attractant** a chemical or agent that lures insects or other pests by stimulating their sense of smell

**attrition** wearing or grinding down of a substance by friction. Dust from such processes contributes to air pollution

**autotroph (primary producer)** an organism that uses sunlight and non-carbon-hydrogen chemical compounds in the environment to make its own food

**background level** the concentration of a substance in an environmental medium (air, water, or soil) that occurs naturally or is not the result of human activities. In exposure assessment, background level is the concentration of a substance in a defined control area, during a fixed period before, during, or after a data-gathering operation

**back pressure** a pressure that can cause water to flow backward into the water supply when a user's wastewater system is at a higher pressure than the public system

**backwashing** reversing the flow of water back through the filter medium to remove entrapped solids and renew its capacity to act as a filter

**backyard composting** diversion of organic food waste and yard trimmings from the municipal waste stream by treating them on private property (backyard) through controlled decomposition of organic matter by bacteria and fungi into a humuslike product. It is considered source reduction, not recycling, because the composted materials never enter the municipal waste stream

**BACT—Best Available Control Technology** an emission limitation based on the maximal degree of emission reduction (considering energy, environmental, and economic impacts) achievable through application of production processes and available methods, systems, and techniques. BACT does not permit emissions in excess of those allowed under any applicable Clean Air Act provisions



**bacteria** (singular bacterium) microscopic single-celled organisms that can aid in pollution control by metabolizing organic matter in sewage, oil spills, or other pollutants. Bacteria in soil, water, or air also can cause diseases that harm humans, animals, and plants

**bactericide** a pesticide used to control or destroy bacteria, typically in the home, schools, or hospitals

**baffle** a flat board or plate, deflector, guide, or similar device constructed or placed in flowing air, water, or slurry systems to cause more uniform flow velocities to absorb energy and to divert, guide, or agitate the flowing material

**baghouse filter** large fabric bag, usually made of glass fibers, used to eliminate intermediate and large (greater than 20 microns in diameter) particles. This device operates as the bag of an electric vacuum cleaner does, passing the air and smaller particles while entrapping the larger ones

**bailer** a pipe with a one-way (check) valve at the lower end, used to remove slurry from the bottom or side of a well as it is being drilled, or to collect groundwater samples from wells or open boreholes

**baling** compacting and tying solid waste into blocks to reduce volume and simplify handling

**bank** the rising slope bordering the side of a stream channel

**barrel sampler** open-ended steel tube that is driven into the ground to collect soil samples with minimal disruption to the structure

**bar screen** in wastewater treatment, a device used to remove large solids

**basal application** in pesticides, the application of a chemical on plant stems or tree trunks just above the soil line

**base** a substance that provides hydroxide anions and has a pH above 7.0

**bean sheet** common term for a pesticide data package record

**bed load** sediment particles resting on or near the channel bottom that are pushed or rolled along by the flow of water

**bench-scale tests** laboratory testing of potential cleanup technologies. See TREATABILITY STUDIES

**benthic or benthos** an organism that feeds on the sediment at the bottom of a water body such as an ocean, lake, or river

**bentonite** a colloidal clay that expands when moist, commonly used to provide a tight seal around a well casing

**Best Available Control Measures (BACM)** a term used to refer to the most effective mea-

asures (according to U.S. Environmental Protection Agency guidance) for controlling small or dispersed particulates and other emissions from sources such as roadway dust, soot, and ash from woodstoves, and open burning of brush, timber, grasslands, or trash

**Best Available Control Technology (BACT)** the most stringent technology available for controlling emissions; major sources are required to use BACT, unless it can be demonstrated that it is not feasible for energy, environmental, or economic reasons

**Best Demonstrated Available Technology (BDAT)** as identified by the U.S. Environmental Protection Agency, the most effective commercially available means of treating specific types of hazardous waste. The BDATs may change with advances in treatment technologies

**Best Management Practice (BMP)** methods that have been determined to be the most effective, practical means of preventing or reducing pollution from nonpoint sources

**beta particle** a high-energy electron emitted by the nucleus of certain types of radioactive atoms

**bioaccumulants** substances that increase in concentration in living organisms as they take in contaminated air, water, or food because the substances are very slowly metabolized or excreted. See BIOLOGICAL MAGNIFICATION

**bioassay** a test to determine the relative strength of a substance by comparing its effect on a test organism with that of a standard preparation

**bioavailability** degree of a substance's ability to be absorbed and to interact with an organism's metabolism

**biodegradable** capable of being decomposed by microorganisms under natural conditions

**biodiversity** refers to the variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different items and their relative frequencies. For biological diversity, these items are organized at many levels, ranging from complete ecosystems to the biochemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, and genetic makeups

**biological contaminants** living organisms or derivatives (e.g., viruses, bacteria, fungi, and mammal and bird antigens) that can cause harmful health effects when inhaled, swallowed, or otherwise taken into the body

**biological control** in pest control, the use of animals and organisms that eat or otherwise kill or outcompete pests

**biological integrity** the ability to support and maintain balanced, integrated functionality in the natural habitat of a given region. The concept is applied primarily in drinking water management

**biologically effective dose** the amount of a deposited or absorbed compound reaching the cells or target sites where the effect will occur, or where the chemical interacts with a membrane

**biological measurement** a measurement taken in a biological medium. For exposure assessment, it is related to the established internal dose of a compound

**biological medium** one of the major components of an organism (e.g., blood, fatty tissue, lymph nodes, or breath) in which chemicals can be stored or transformed

**biological oxidation** decomposition of complex organic materials by microorganisms. Occurs in self-purification of water bodies and in activated sludge wastewater treatment

**biological oxygen demand (BOD or BOD5)** an indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic waste

**biological pesticides** certain microorganisms, including bacteria, fungi, viruses, and protozoa, that are effective at controlling pests. These agents usually do not have toxic effects on animals and people and do not leave toxic or persistent chemical residues in the environment

**biological stressors** organisms accidentally or intentionally dropped into habitats in which they did not naturally evolve (e.g., gypsy moths, Dutch elm disease, certain types of algae, and bacteria) but will damage and degrade

**biological treatment** a treatment technology that uses bacteria to consume organic waste

**biomass** all of the living material in a given area; often refers to vegetation

**biome** entire community of interacting living organisms that have adapted to a single major ecological area

**biomonitoring** the use of living organisms to test the suitability of treated wastewater for discharge into receiving waters and to test the quality of such waters downstream from the discharge

**biosphere** the portion of Earth and its hydrosphere and atmosphere that can support life

**biostabilizer** a machine that converts solid waste into compost by grinding and aeration

**biota** the animal and plant life (all living organisms) of a given region

**biotechnology** techniques and processes that use living organisms or parts of organisms to produce a variety of products (from medicines to industrial enzymes), to improve plants or animals, to develop microorganisms to remove toxics from bodies of water, or to act as pesticides

**biotic community** a naturally occurring assemblage of plants and animals that live in the same environment and are mutually sustaining and interdependent

**biotransformation** conversion of a substance into other compounds by organisms; includes biodegradation

**blackwater** water that contains animal, human, or food waste

**bloom** a proliferation of algae and/or higher aquatic plants in a body of water; often related to pollution, especially when pollutants accelerate growth

**body burden** the amount of a chemical stored in the body at a given time, especially a potential toxin in the body as the result of exposure

**bog** a type of wetland that accumulates appreciable peat deposits. Bogs depend primarily on precipitation for their water source and are usually acidic and rich in plant residue with a conspicuous mat of living green moss

**boiler** a vessel designed to transfer heat produced by combustion or electric resistance to water. Boilers may provide hot water or steam

**boom** an elongate floating device (arm) used to contain oil on a body of water by physically blocking it for removal

**borehole** hole in the ground extending below the surface made with drilling equipment

**botanical pesticide** a pesticide whose active ingredient is a plant-produced chemical such as nicotine or strychnine. Also called a plant-derived pesticide

**bottom ash** the nonairborne combustion residue from burning pulverized coal in a boiler; the material that falls to the bottom of the boiler and is removed mechanically; a concentration of noncombustible materials, which may include toxic materials

**bounding estimate** an estimate of exposure, dose, or risk that is higher than that incurred by the person in the population with the currently highest exposure, dose, or risk. Bounding estimates are useful in developing statements that exposures, doses, or risks are not greater than an estimated value

**brackish water** a mix of freshwater and salt water such as that in an estuary

**breakthrough** a crack or break in a filter bed that allows the passage of floc or particulate mat-

ter through a filter. It can cause an increase in turbidity

**breathing zone** area of air in which an organism inhales

**breeder reactor** a fission reactor that generates more fissionable atoms, which are, in turn, consumed in subsequent reactions

**brine mud** waste material, often associated with well drilling or mining, composed of mineral salts or other inorganic compounds

**British thermal unit (BTU)** unit of heat energy equal to the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit at sea level

**broadcast application** the spreading of pesticides over an entire area rather than the individual applications where needed

**bubble** a system under which existing air emissions sources can propose alternate means to comply with a set of air emissions limitations. Under the bubble concept, sources can control more than required at one emission point where control costs are relatively low in return for a comparable relaxation of controls at a second emission point where control costs may be higher

**buffer** a solution or liquid whose chemical makeup is such that it minimizes changes in pH when acids or bases are added to it. Water can also be buffered to the chemistry of the surrounding rock or soil through chemical reactions that exchange ions in the water with those in the surrounding medium

**buffer strips** strips of grass or other erosion-resisting vegetation between or below cultivated strips or fields

**building cooling load** the hourly amount of heat that must be removed from a building to maintain indoor comfort (measured in British thermal units [BTUs])

**building envelope** the exterior surface of a building's construction: the walls, windows, floors, roof, and floor. Also called the building shell

**bulk sample** a small portion (usually thumbnail size) of a suspect asbestos-containing building material collected by an asbestos inspector for laboratory analysis to determine asbestos content. Also a sample of rock or soil that is representative of the chemistry of the entire body

**bulky waste** large items of waste materials, such as appliances, furniture, large auto parts, trees, stumps

**burial ground (graveyard)** a disposal site for radioactive waste materials that uses earth or water as a shield

**by-catch** the portion of a commercial fishing catch that consists of unintentionally caught species

**by-product** material, other than the principal product, generated as a consequence of an industrial process or as a breakdown product in a living system

**cap** a layer of clay or other impermeable material installed over the top of a closed landfill or encapsulated waste material to prevent entry of rainwater and minimize leachate

**capacity** the maximum quantity of sediment that a stream can carry

**capillary action** movement of water through very small spaces due to molecular forces called capillary forces

**capillary fringe** the porous material just above the water table that may hold water by capillarity (a property of surface tension that draws water upward) in the smaller void spaces. The zone above the water table within which the porous medium is saturated by water under less than atmospheric pressure

**carbon absorber** an add-on control device that uses activated carbon to absorb volatile organic compounds (VOCs) from a gas stream. The VOCs are later recovered from the carbon

**carbon adsorption** a treatment system that removes contaminants from groundwater or surface water by forcing it through tanks containing activated carbon treated to attract the contaminants

**carbon cycle** a nutrient and chemical exchange cycle consisting of the routes that carbon takes through the Earth's environmental systems

**carboxyhemoglobin** hemoglobin in which the iron is bound to carbon monoxide (CO) instead of oxygen

**carcinogen** any substance that can cause an increased incidence of cancer

**carrier** the inert liquid or solid material in a pesticide product that serves as a delivery vehicle for the active ingredient. Carriers do not have toxic properties of their own. Also, any material or system that can facilitate the movement of a pollutant into the body or cells

**carrying capacity** in recreation management, the amount of use a recreation area can sustain without loss of quality. In wildlife management, the maximal number of animals an area can support during a given period

**cask** a thick-walled container (usually lead) used to transport radioactive material. Also called a coffin

**CAS registration number** a number assigned by the Chemical Abstract Service to identify a chemical

**catalyst** a substance that changes the speed or yield of a chemical reaction or drives a chemical reaction without being consumed or chemically changed by the chemical reaction

**catalytic converter** an air pollution abatement device that removes pollutants from motor vehicle exhaust, by either oxidizing them into carbon dioxide and water or reducing them to nitrogen

**catalytic incinerator** a control device that oxidizes volatile organic compounds (VOCs) by using a catalyst to promote the combustion process. Catalytic incinerators require lower temperatures than conventional thermal incinerators, thus saving fuel and other costs

**categorical exclusion** a class of actions that either individually or cumulatively would not have a significant effect on the human environment and, therefore, would not require preparation of an Environmental Assessment (EA) or Environmental Impact Statement (EIS) under the National Environmental Policy Act (NEPA)

**categorical pretreatment standard** a technology-based wastewater limitation for an industrial facility discharging into a municipal sewer system. Analogous in stringency to Best Available Technology (BAT) for direct dischargers

**cathode** the positively charged electrode in a cell where reduction occurs

**cathodic protection** a technique to prevent corrosion of a metal surface by making it the cathode of an electrochemical cell

**cation** an ion that has a positive charge as the result of electron loss from the shell. It can be an element or compound

**cavitation** the formation and collapse of gas pockets or bubbles on the blade of an impellers, the gate of a valve, or in an ultrasonic cleaner; collapse of these pockets or bubbles drives water with such force that it can cause pitting of the gate or valve surface

**cells** in solid waste disposal, holes where waste is dumped, compacted, and covered with layers of dirt on a daily basis. In biology, the smallest structural part of living matter capable of functioning as an independent unit

**cementitious** densely packed and nonfibrous friable materials

**central collection point** location where a generator of regulated medical waste consolidates wastes originally generated at various locations in the facility. The wastes are gathered together for treatment on-site or for transportation elsewhere for treatment and/or disposal. This term

could also apply to community hazardous waste collections and industrial and other waste management systems

**centrifugal collector** a mechanical system using centrifugal force to remove aerosols from a gas stream or to remove water from sludge

**CERCLIS** the federal Comprehensive Environmental Response, Compensation, and Liability Information System, a database that includes all sites that have been nominated for investigation by the Superfund program and inclusion on the National Priorities List (NPL)

**chain of custody (COC)** documentation used to describe how environmental samples were managed from the time of collection through delivery to the laboratory and subsequent receipt of a written analytical report

**channelization** straightening and deepening streams so water will move faster. A marsh-drainage tactic that can interfere with waste assimilation capacity, disturb fish and wildlife habitats, and aggravate flooding

**characteristic** any one of the four categories used in defining hazardous waste; ignitability, corrosivity, reactivity, and toxicity

**characterization of ecological effects** part of ecological risk assessment that evaluates ability of an environmental stressor to cause adverse effects under given circumstances

**characterization of exposure** portion of an ecological risk assessment that evaluates interaction of a stressor with one or more ecological entities

**check-valve tubing pump** water sampling tool also referred to as a water pump

**chemical bond** the linkage between atoms by electron interactions in molecules and between molecules and ions in crystals

**chemical compound** a distinct and pure substance formed by the union of two or more elements in definite proportion by charge and atomic radius

**chemical element** a fundamental substance comprising a specific type of atom with characteristic atomic mass, charge, and radius; the simplest form of matter

**chemical oxygen demand (COD)** a measure of the oxygen required to oxidize all compounds, both organic and inorganic, in a given sample of water

**chemical stressors** chemicals released to the environment through industrial waste, auto emissions, pesticides, and other human activity that can cause illnesses and even death in plants and animals



**chemical treatment** any one of a variety of methods and technologies that use chemicals or a variety of chemical processes to treat waste

**chemosterilant** a chemical that controls pests by preventing reproduction

**chemosynthesis** a process in which an organism uses energy from reactions of certain chemicals and is not dependent upon photosynthesis

**chiller** a device that generates a cold liquid that is circulated through an air-handling unit's cooling coil to cool the air supplied to the building

**chilling effect** the lowering of the Earth's temperature because increased particles in the air block the Sun's rays

**chisel plowing** preparing croplands by using a special implement that avoids complete inversion of the soil, as in conventional plowing. Chisel plowing can leave a protective cover or crop residues on the soil surface to help prevent erosion and improve filtration

**chlorinated hydrocarbons** chemicals containing only chlorine, carbon, and hydrogen. These include a class of persistent, broad-spectrum insecticides that linger in the environment and accumulate in the food chain. Among them are DDT, aldrin, dieldrin, heptachlor, chlordane, lindane, endrin, Mirex, hexachloride, and toxaphene. Other examples include TCE, used as an industrial solvent. Also, any chlorinated organic compounds including chlorinated solvents such as dichloromethane, trichloromethylene, or chloroform

**chlorination** the application of chlorine to drinking water, sewage, or industrial waste to disinfect or to oxidize undesirable compounds

**chlorinator** a device that adds chlorine, in gas or liquid form, to water or sewage to kill infectious bacteria

**chlorine-contact chamber** that part of a water treatment plant where effluent wastewater is disinfected by chlorine

**chlorofluorocarbons (CFCs)** a family of inert, nontoxic, and easily liquefied chemicals used in refrigeration, air-conditioning, packaging, or insulation, or as solvents and aerosol propellants. CFCs are not destroyed in the lower atmosphere and can drift into the upper atmosphere, where their chlorine components destroy ozone. They are regulated under the Montreal Protocol

**chlorophenoxyl** a class of herbicides that may be found in domestic water supplies and cause adverse health effects

**chlorosis** discoloration of normally green plant parts caused by disease, lack of nutrients, or various air pollutants

**cholinesterase** an enzyme found in animals that regulates nerve impulses by the inhibition of acetylcholine. Cholinesterase inhibition is associated with a variety of acute symptoms, such as nausea, vomiting, blurred vision, stomach cramps, and rapid heart rate

**chromatography** an analytical technique that employs two materials, one moving and one stationary, to separate a mixture into its components. The form can be gas or liquid chromatography

**chronic effect** an adverse effect on a human or animal in which symptoms recur frequently or develop slowly over a long period

**chronic exposure** multiple exposures or continuous exposure to a substance over an extended period or over a significant fraction of an animal or human lifetime, usually seven years to a lifetime

**chronic toxicity** the capacity of a substance to cause long-term poisonous health effects in humans, animals, fish, and other organisms

**cistern** small tank or storage facility used to store water for a home or farm; often used to store rainwater

**clarification** clearing action that occurs during wastewater treatment when solids settle out. This is often aided by centrifugal action and chemically induced coagulation in wastewater

**clarifier** a tank in which solids settle to the bottom and are subsequently removed as sludge

**class I area** under the Clean Air Act, a class I area is one in which visibility is protected more stringently than under the National Ambient Air Quality Standards; includes national parks, wilderness areas, monuments, and other areas of special national and cultural significance

**class I substance** one of several groups of chemicals with an ozone depletion potential of 0.2 or higher, including CFCs, halons, carbon tetrachloride, and methyl chloroform (listed in the Clean Air Act) and HBFCs and ethyl bromide (added by EPA regulations)

**class II substance** a substance with an ozone depletion potential of less than 0.2. All HCFCs are currently included in this classification

**clean coal technology** any technology not in widespread use prior to the Clean Air Act Amendments of 1990. The use of clean coal technology is intended to achieve significant reductions in pollutants associated with the burning of coal

**clean fuels** blends or substitutes for gasoline fuels, including compressed natural gas, methanol, ethanol, and liquefied petroleum gas designed to reduce emission of air pollutants

**cleanup** actions taken to deal with a release or threat of release of a hazardous substance that could affect humans and/or the environment. The term *cleanup* is sometimes used interchangeably with the terms *remedial action*, *removal action*, *response action*, and *corrective action*

**clear-cut** harvesting all the trees in one area at one time, a practice that can encourage fast rainfall or snowmelt runoff, erosion, sedimentation of streams and lakes, and flooding and destroys vital habitat

**clear well** a reservoir for storing filtered water of sufficient quantity to eliminate the need to vary the filtration rate with variations in demand. Also used to provide chlorine contact time for disinfection

**climate** the composite pattern of long-term weather conditions that can be expected in a given region

**climate change** (also referred to as global climate change) the term *climate change* is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, *climate change* has been used synonymously with the term *global warming*; scientists, however, tend to use the term in the wider sense to include natural changes in climate

**cloning** in biotechnology, obtaining a group of genetically identical cells from a single cell; making identical copies of a gene

**closed-loop recycling** reclaiming or reusing wastewater for nonpotable purposes in an enclosed process

**closed system** a system (network of biotic and abiotic relationships) that is isolated and self-contained

**closure** the procedure an operator must follow when a landfill reaches its legal capacity for acceptance of solid waste

**coagulation** clumping of particles in wastewater to settle out impurities, often induced by chemicals such as lime, alum, and iron salts

**coal cleaning technology** a precombustion process by which coal is physically or chemically treated to remove some of its sulfur and reduce sulfur dioxide emissions

**coal gasification** conversion of coal to a gaseous product by one of several available technologies

**coastal zone** lands and waters adjacent to the coastline of a landmass that exert an influence on the uses of the sea and its ecology, or whose uses and ecology are affected by the sea

**Code of Federal Regulations (CFR)** document that codifies all rules of the executive departments and agencies of the federal government. It is divided into 50 volumes, known as titles. Title 40 of the CFR (referenced as 40 CFR) lists all environmental regulations

**Coefficient of Haze (COH)** a measurement of visibility interference in the atmosphere

**cofire** burning of two fuels in the same combustion unit (e.g., coal and natural gas, or oil and coal)

**cogeneration** the consecutive generation of useful thermal and electric energy from the same fuel source

**coke** the solid residue of impure carbon obtained from bituminous coal and other carbonaceous materials after removal of volatile material by destructive distillation. It is used as a fuel and in making steel

**coke oven** an industrial oven that converts coal into coke, one of the basic materials used in blast furnaces for the conversion of iron ore into iron

**cold temperature CO** a standard for automobile emissions of carbon monoxide (CO) emissions to be met at a low temperature (i.e., 20°F Fahrenheit). Conventional automobile catalytic converters are not efficient in cold weather until they warm up

**Coliform Index** a rating of the purity of water based on a count of fecal bacteria

**coliform organism** microorganism found in the intestinal tract of humans and animals. Its presence in water indicates fecal pollution and potentially adverse contamination by pathogens

**collector** public or private hauler that collects nonhazardous waste and recyclable materials from residential, commercial, institutional, and industrial sources

**collector sewers** pipes used to collect and carry wastewater from individual sources to an interceptor sewer that will carry it to a treatment facility

**colloids** very small, finely disseminated solids (that do not dissolve) that remain dispersed in a liquid for a long time because of their small size and electrical charge

**combined sewer overflows** discharge of a mixture of storm water and domestic waste when the flow capacity of a sewer system is exceeded during rainstorms or other floods

**combined sewers** a sewer system that carries both sewage and storm-water runoff. Normally, its entire flow goes to a waste treatment plant, but during a heavy storm or thaw, the volume of water may cause overflow of untreated mixtures of storm water and sewage into receiving

waters. Storm-water runoff may also carry toxic chemicals from industrial areas or streets into the sewer system

**combustion** burning, or rapid oxidation, accompanied by release of energy in the form of heat and light. Also refers to controlled burning of waste, in which heat chemically alters organic compounds, converting them into stable inorganic compounds such as carbon dioxide and water

**combustion chamber** the actual compartment where waste is burned in an incinerator

**combustion product** substance produced during the burning or oxidation of a material

**command-and-control regulations** specific requirements prescribing how to comply with specific standards defining acceptable levels of pollution

**commensalism** a relationship between species in which one organism benefits and the other is unaffected (e.g., one plant living on the surface of another)

**comment period** time provided for the public to review and comment on a proposed EPA action or rule making after publication in the Federal Register

**commercial waste** all solid waste emanating from business establishments such as stores, markets, office buildings, restaurants, shopping centers, and theaters

**commercial waste management facility** a treatment, storage, disposal, or transfer facility that accepts waste from a variety of sources, as compared to a private facility, which normally manages a limited waste stream generated by its own operations

**comminuter** a machine that shreds or pulverizes solids to make waste treatment easier

**comminution** mechanical shredding or pulverizing of waste. Used in both solid waste management and wastewater treatment

**commonsense initiative** voluntary program to simplify environmental regulation to achieve cleaner, cheaper, smarter results, starting with six major industry sectors

**community** in ecology, an assemblage of populations of different species within a specified location in space and time. Sometimes, a particular subgrouping may be specified, such as the fish community in a lake or the soil arthropod community in a forest

**community relations** the EPA effort to establish two-way communication with the public to create understanding of EPA programs and related actions, to ensure public input into decision-

making processes related to affected communities, and to make certain that the agency is aware of and responsive to public concerns. Specific community relations activities are required in relation to Superfund remedial actions

**community water system** a public water system that has at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents

**compact fluorescent lamp (CFL)** small fluorescent lamp used as more efficient alternative to incandescent lighting. Also called PL, CFL, Twin-Tube, or BIA-X lamps

**compaction** reduction of the bulk of solid waste by rolling and tamping

**comparative risk assessment** a process that generally uses the judgment of experts to predict effects and set priorities among a wide range of environmental problems

**competence** a measure of the largest particles that a stream can transport

**compliance coal** any coal that emits less than 1.2 pounds of sulfur dioxide per million BTU when burned. Also known as low-sulfur coal

**compliance monitoring** collection and evaluation of data, including self-monitoring reports, and verification to show whether pollutant concentrations and loads contained in permitted discharges are in compliance with the limits and conditions specified in the permit

**compliance schedule** a negotiated agreement between a pollution source and a government agency that specifies dates and procedures by which a source will reduce emissions and, thereby, comply with a regulation

**composite sample** a series of water samples taken over a given period and weighted by flow rate

**composting** the controlled biological decomposition of organic material in the presence of air to form a humus-like material. Controlled methods of composting include mechanical mixing and aerating, ventilating the materials by dropping them through a vertical series of aerated chambers, or placing the compost in piles out in the open air and mixing it or turning it periodically

**composting facilities** an off-site facility where the organic component of municipal solid waste is decomposed under controlled conditions. Also, an aerobic process in which organic materials are ground or shredded and then decomposed to humus in windrow piles (long rows) or in mechanical digesters, drums, or similar enclosures

**compound** a substance that can be decomposed into its elements by chemical processes

**concentration** the relative amount of a substance mixed with another substance. An example is five parts per million of carbon monoxide in air or 1 mg/L of iron in water

**condensate** water created by cooling steam or water vapor

**condensation** the conversion of a gas into a liquid

**conditionally exempt generators (CE)** persons or enterprises that produce less than 220 pounds (100 kg) of hazardous waste per month. Exempt from most regulation, they are required merely to determine whether their waste is hazardous, notify appropriate state or local agencies, and ship it by an authorized transporter to a permitted facility for proper disposal

**conductance** a rapid method of estimating the dissolved solids content of water supply by determining the capacity of a water sample to carry an electrical current. Conductivity is a measure of the ability of a solution to carry an electrical current

**conduction** the transport of heat by atomic or molecular motion

**conductivity** a measure of the ability of a solution to carry an electrical current

**cone of depression** a depression or lowering in the water table in an inverted cone shape that develops around a pumping well

**cone penetrometer testing (CPT)** a direct push system used to measure lithology based on soil penetration resistance. Sensors in the tip of the cone of the direct push rod measure tip resistance and sidewall friction, transmitting electrical signals to digital processing equipment on the ground surface

**confidential business information (CBI)** material that contains trade secrets or commercial or financial information that has been claimed as confidential by its source (e.g., a pesticide or new chemical formulation registrant). The EPA has special procedures for handling such information

**consent decree** a legal document, approved by a judge, that formalizes an agreement reached between EPA and potentially responsible parties (PRPs) of a Superfund site through which PRPs will conduct all or part of a cleanup action, to cease or correct actions or processes that are polluting the environment, or otherwise comply with EPA-initiated regulatory enforcement actions to resolve the contamination at the Superfund site involved. The consent decree

describes the actions PRPs will take and may be subject to a public comment period

**conservation** preserving and renewing, when possible, human and natural resources. The use, protection, and improvement of natural resources according to principles that will ensure their highest economic or social benefits

**conservation easement** an easement restricting or limiting a landowner to land uses that are compatible with long-term conservation and environmental values

**constituent(s) of concern** specific chemical identified for evaluation in the site assessment process

**construction and demolition waste** waste building materials, dredging materials, tree stumps, and rubble resulting from construction, remodeling, repair, and demolition of homes, commercial buildings, and other structures and pavements. May contain lead, asbestos, or other hazardous substances

**construction ban** if, under the Clean Air Act, the EPA disapproves an area's planning requirements for correcting nonattainment, the EPA can ban the construction or modification of any major stationary source of the pollutant for which the area is in nonattainment

**consumptive water use** water removed from available supplies without return to a water resources system (e.g., water used in manufacturing, agriculture, and food preparation)

**contact pesticide** a chemical that kills pests when it touches them, instead of by ingestion

**contaminant** any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil

**contamination** introduction into water, air, and soil of microorganisms, chemicals, toxic substances, wastes, or wastewater in a concentration that makes the medium unfit for its current or intended use. Also applies to surfaces of objects, buildings, and various household and agricultural products

**continental margin** the region between the shoreline of a continent and the deep ocean basins including the continental shelf, continental slope, and continental rise

**continental rise** an apron of sediment between the continental slope and the deep seafloor that is shallower in slope than the continental slope but steeper than the abyssal plain

**continental slope** the relatively steep underwater slope between the continental shelf and the continental rise



- contingency plan** a document setting out an organized, planned, and coordinated course of action to be followed in case of a fire, explosion, or other accident that releases toxic chemicals, hazardous waste, or radioactive materials that threaten human health or the environment
- continuous discharge** a routine release to the environment that occurs without interruption, except for infrequent shutdowns for maintenance, process changes, etc.
- contour plowing** soil tilling method that follows the shape of the land to minimize erosion
- contour strip farming** a type of contour farming in which row crops are planted in strips, between alternating strips of close-growing, erosion-resistant forage crops
- contract labs** laboratories under contract to the EPA, that analyze samples taken from waste, soil, air, and water or carry out research projects
- controlled reaction** a chemical reaction under temperature and pressure conditions maintained within safe limits to produce a desired product or process
- control rod** a column of neutron-absorbing alloys that are spaced among fuel rods to manage (control) nuclear fission reactions
- convection** the transport of heat by the movement of thermally driven density currents in air, water, or liquid
- conventional pollutants** statutorily listed pollutants understood well by scientists. These may be in the form of organic waste, sediment, acid, bacteria, viruses, nutrients, oil and grease, or heat
- conventional tilling** tillage operations considered standard for a specific location and crop and that tend to bury the crop residues; usually considered as a base for determining the cost-effectiveness of control practices
- conveyance loss** water loss in pipes, channels, conduits, or ditches by leakage or evaporation
- cooling tower** a device that dissipates the heat from water-cooled systems by spraying the water through streams of rapidly moving air
- Copenhagen Accord** a 2009 international agreement to reduce carbon emissions by 2020
- core** the uranium-containing center of a nuclear reactor, where energy is released
- corrective action** the EPA can require treatment, storage, and disposal facilities (TSDF) that handle hazardous waste to undertake corrective actions to clean up spills resulting from failure to follow hazardous waste management procedures or other mistakes
- corrosion** the alteration and dissolution of a metal surface caused by a chemical reaction such as between water and pipes, chemicals touching a metal surface, or contact between two metals
- corrosive** a chemical agent (acid) that reacts with the surface of a material, causing it to deteriorate
- cost/benefit analysis** a quantitative evaluation of the costs that would have been incurred by implementing an environmental regulation versus the overall benefits to society of the proposed action
- cost-effective alternative** an alternative control or corrective method identified after analysis as being the best available in terms of reliability, performance, and cost. Although costs are one important consideration, regulatory and compliance analysis does not require EPA to choose the least expensive alternative. For example, when selecting or approving a method for cleaning up a Superfund site, EPA balances costs with the long-term effectiveness of the methods proposed and the potential danger posed by the site
- cost recovery** a legal process by which potentially responsible parties who contributed to contamination at a Superfund site can be required to reimburse the trust fund for money spent during any cleanup actions by the federal government
- cost sharing** a publicly financed program through which society, as a beneficiary of environmental protection, shares part of the cost of pollution control with those who must actually install the controls. In Superfund, for example, the government may pay part of the cost of a cleanup action and those responsible for the pollution pay the major share
- covalent bond** the bond that arises from atoms sharing electrons
- cover crop** a crop that provides temporary protection for delicate seedlings and/or provides a cover canopy for seasonal soil protection and nourishment between normal crop production periods
- cover material** soil used to cover compacted solid waste in a sanitary landfill
- cradle-to-grave or manifest system** a procedure in which hazardous materials are identified and tracked as they are produced, treated, transported, and disposed of by a series of permanent, linkable, descriptive documents (e.g., manifests). Commonly referred to as the cradle-to-grave system
- criteria** descriptive factors taken into account by EPA in setting standards for various pollutants. These factors are used to determine limits on allowable concentration levels and to limit the number of violations per year. When issued by EPA, the criteria provide guidance to the states on how to establish their standards

**criteria pollutants** the 1970 amendments to the Clean Air Act required the EPA to set National Ambient Air Quality Standards (NAAQS) for certain pollutants known to be hazardous to human health. The EPA identified and set standards to protect human health and welfare for six pollutants: ozone, carbon monoxide, total suspended particulates, sulfur dioxide, lead, and nitrogen oxide. The term *criteria pollutants* derives from the requirement that EPA describes the characteristics and potential health and welfare effects of these pollutants. It is on the basis of these criteria that standards are set or revised

**critical effect** the first adverse effect, or its known precursor, that occurs as a dose rate increases. Designation is based on evaluation of overall database

**critical mass** the minimal mass of fissionable material needed for a chain nuclear reaction to be self-sustained (e.g., one neutron formed by a fission is used to induce a second fission)

**crop rotation** planting a succession of different crops on the same land, as opposed to planting the same crop every season

**cross-connection** any actual or potential connection between a drinking water system and a water supply that is not approved for public consumption (i.e., sanitary sewer pipe) or other source of contamination

**cross-contamination** the movement of underground contaminants from one level or area to another due to invasive subsurface activities

**crude oil** the oil that is taken directly out of the ground is an unrefined mixture of hundreds of different hydrocarbons formed by the conversion of organic compounds by using heat and pressure. A fossil fuel

**crumb rubber** ground rubber fragments the size of sand or silt used in rubber or plastic products, or processed further into reclaimed rubber or asphalt products

**cubic feet per minute (CFM)** a measure of the volume of a substance flowing through air within a fixed period. With regard to indoor air, it refers to the amount of air that is exchanged with outdoor air in a minute's time (i.e., the air exchange rate)

**cullet** crushed glass

**cultures and stocks** infectious agents and associated biologicals including cultures from medical and pathological laboratories, agents from research and industrial laboratories, waste from the production of biologicals, discarded live and attenuated vaccines, and culture dishes

and devices used to transfer, inoculate, and mix cultures

**cumulative ecological risk assessment** consideration of the total ecological risk from multiple stressors to a given ecozone

**cumulative exposure** the sum of exposures of an organism to a pollutant over a period

**cuttings** piles of waste rock and/or sediment removed through the progressive drilling of a conventional well with hollow-stem auger or rotary drilling equipment that were returned to the surface to clear the well bore. Mainly associated with oil and gas wells

**cyclone collector** a spinning device that is cylindrical on top and conical on the bottom and uses centrifugal force to remove large particles from polluted air by forcing them to the walls of the cylinder before allowing them to settle to a collector in the bottom of the cone

**data quality objectives (DQOs)** qualitative and quantitative statements of the overall level of uncertainty that a decision maker will accept in results or decisions based on environmental data. They provide the statistical framework for planning and managing environmental data operations consistently with the user's need

**deadmen** anchors drilled or cemented into the ground to provide additional reactive mass for direct push sampling rigs

**decant** to draw off the upper layer of liquid after the heaviest material (a solid or another liquid) has settled

**decay products** the by-products of the decay of radioactive materials, often referred to as "daughters" or "progeny." The radon 222 decay products of most concern from a public health standpoint are polonium 214 and polonium 218

**dechlorination** removal of chlorine from a substance

**decomposer** an organism such as a fungus or bacterium that degrades nonliving matter into simpler constituents that can then be utilized by plants

**decomposition** the breakdown of matter by bacteria and fungi, changing the chemical makeup and physical appearance of materials

**decontamination** removal of harmful substances such as noxious chemicals, disease-causing bacteria or other organisms, or radioactive material from exposed individuals, rooms, and furnishings in buildings or the exterior environment

**deep-well injection** deposition of raw or treated, filtered hazardous waste by pumping it into wells that are much deeper than any public water supply, where it is contained in the pores of permeable subsurface rock

**deflocculating agent** a material added to a suspension to prevent settling

**defluoridation** the removal of excess fluoride in drinking water to prevent the staining of teeth

**defoliant** an herbicide that removes leaves from trees and growing plants

**deforestation** the clearing and permanent loss of forest and forest-related ecosystems. Done primarily for agriculture but also development

**degasification** a water treatment that removes dissolved gases from the water

**degree-day** a rough measure used to estimate the amount of heating required in a given area. It is defined as the difference between the average (mean) daily temperature and 65°F (18.3°C). Degree-days also are calculated to estimate cooling requirements

**delist** use of the petition process to have a facility's toxic designation rescinded

**demand-side waste management** prices whereby consumers use purchasing decisions to communicate to product manufacturers that they prefer environmentally sound products packaged with the least amount of waste, made from recycled or recyclable materials, and containing no hazardous substances

**demineralization** a treatment process that removes dissolved minerals from water

**denitrification** the biological reduction of nitrate to nitrogen gas by denitrifying bacteria in soil

**density** a measure of mass per unit volume of material or how massive a specific volume of a solid, liquid, or gas is in comparison to the same volume of water

**depressurization** a condition that occurs when the air pressure inside a structure is lower than the air pressure outdoors. Depressurization can occur when household appliances such as fireplaces or furnaces, which consume or exhaust house air, are not supplied with enough makeup air. Radon may be drawn into a house more rapidly under depressurized conditions

**dermal absorption or penetration** process by which a chemical penetrates the skin and enters the body as an internal dose

**dermal toxicity** the ability of a pesticide or toxic chemical to poison people or animals by contact with the skin

**DES** a synthetic estrogen, diethylstilbestrol. It is used as a growth stimulant in food animals. Residues in meat are thought to be carcinogenic

**desalination** removal of salts from ocean or brackish water. Also, removal of salts from soil by artificial means, usually leaching

**desiccant** a chemical agent that absorbs moisture and dries materials. Some desiccants are capable of drying out plants or insects, causing death

**designated pollutant** an air pollutant that is neither a criteria nor hazardous pollutant, as described in the Clean Air Act, but for which new source performance standards exist. The Clean Air Act does require states to control these pollutants, such as acid mist, total reduced sulfur (TRS), and fluorides

**designated uses** those water uses identified in state water quality standards that must be achieved and maintained as required under the Clean Water Act. Uses can include cold water fisheries, public water supply, and irrigation

**design capacity** the average daily flow of liquid or air that a treatment plant or other facility is designed to accommodate

**designer bugs** popular term for microbes developed through biotechnology (genetic engineering) that can degrade specific toxic chemicals of interest at their source in toxic waste dumps or in groundwater

**destination facility** the facility to which regulated medical waste is shipped for treatment and destruction, incineration, and/or disposal

**destratification** vertical mixing within a lake or reservoir to eliminate separate layers of temperature, plant, or animal life totally or partially

**destroyed medical waste** regulated medical waste that has been ruined, torn apart, or mutilated through thermal treatment, melting, shredding, grinding, tearing, or breaking, so that it is no longer generally recognized as medical waste but has not yet been treated (excludes compacted regulated medical waste)

**destruction and removal efficiency (DRE)** a percentage that represents the number of molecules of a compound removed or destroyed in an incinerator relative to the number of molecules entering the system (e.g., a DRE of 99.99 percent means that 9,999 molecules are destroyed for every 10,000 that enter; 99.99 percent is known as four nines. For some pollutants, the removal requirement may be as stringent as "six nines")

**destruction facility** a facility that destroys regulated medical waste

**desulfurization** removal of sulfur from fossil fuels to reduce pollution

**detectable leak rate** the smallest leak from a storage tank, expressed in terms of gallons or liters per hour, that a test can reliably discern with a certain probability of detection or false alarm

- detection criterion** a predetermined rule to ascertain whether a tank is leaking or not. Most volumetric tests use a threshold value (0.05 gallon per hour) as the detection criterion
- detection limit** the lowest concentration of a chemical that can reliably be distinguished from a zero concentration
- detention time** the theoretical calculated time required for a small amount of water to pass through a tank at a given rate of flow. Also, the actual time that a small amount of water is in a settling basin, flocculating basin, or rapid-mix chamber. In storage reservoirs, it is the length of time water will be held before being used
- detritivore** an organism that consumes the waste products or dead bodies of other organisms
- development effects** adverse effects such as altered growth, structural abnormality, or functional deficiency observed in a developing organism
- dewater** removal or separation of a portion of the water in a sludge or slurry to dry the sludge so it can be handled and disposed of. Also, to remove or drain water from a tank or trench
- diatomaceous earth (diatomite)** a chalklike material (fossilized diatoms) used to filter out solid waste in wastewater treatment plants. Also used as an active ingredient in some powdered pesticides
- dicofol** a pesticide used on citrus fruits
- diffused air** a type of aeration process that forces oxygen into sewage by pumping air through perforated pipes inside a holding tank
- diffusion** the movement of suspended or dissolved particles (or molecules) from an area of higher concentration to an area of lower concentration. The process tends to distribute the particles or molecules more uniformly
- digester** in wastewater treatment, a closed tank. In solid-waste conversion, a unit in which bacterial action is induced and accelerated in order to break down organic matter and establish the proper carbon-to-nitrogen ratio
- digestion** the biochemical decomposition of organic matter, resulting in partial gasification, liquefaction, and mineralization of pollutants
- dike** a low wall that can act as a barrier to prevent a spill from spreading. A trench cut into the surface. In geology, a sheetlike intrusive igneous rock that cuts across the strata of the surrounding rock
- dilutents** any liquid or solid material used to dilute or carry an active ingredient
- dilution ratio** the fraction or percentage of the volume of water in a stream versus the volume of incoming water. It affects the ability of the stream to assimilate waste
- dimictic** lakes and reservoirs that freeze over and normally go through two stratifications and two mixing cycles a year
- dinocap** a fungicide used primarily by apple growers to control summer diseases. EPA proposed restrictions on its use in 1986 when laboratory tests found it caused birth defects in rabbits
- dinoseb** a herbicide that is also used as a fungicide and insecticide. It was banned by EPA in 1986 because it posed the risk of birth defects and sterility
- direct discharger** a municipal or industrial facility that introduces pollution through a defined conveyance or system such as outlet pipes
- direct filtration** a method of treating water that consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration
- direct push** technology used for performing subsurface investigations by driving, pushing, and/or vibrating small-diameter hollow steel rods into the ground. Also known as direct drive, drive point, or push technology
- direct runoff** water that flows over the ground surface directly into streams, rivers, and lakes
- discharge** the quantity of fluid or gas past a specific point equal to velocity multiplied by the cross-sectional area through which it flows. Flow of surface water in a stream or canal or the outflow of groundwater from a flowing artesian well, ditch, or spring. The term can also apply to discharge of liquid-treated wastewater from a facility or to chemical emissions into the air through designated venting mechanisms
- disinfectant** a chemical or physical process that kills pathogenic organisms in water, in air, or on surfaces. Chlorine often is used to disinfect sewage treatment effluent, water supplies, wells, and swimming pools
- disinfectant by-product** a compound formed by the reaction of a disinfectant such as chlorine with organic material in the water supply. Also, a chemical by-product of the disinfection process
- disinfectant time** the time it takes water to move from the point of disinfectant application (or the previous point of residual disinfectant measurement) to a point before or at the point where the residual disinfectant is measured. In pipelines, the time is calculated by dividing the internal volume of the pipe by the maximal hourly flow rate. Within mixing basins and storage reservoirs, it is determined by tracer studies or an equivalent demonstration



**dispersant** a chemical agent used to break up concentrations of organic material such as spilled oil so that it can be further chemically or biologically degraded

**disposal** final placement or destruction of toxic, radioactive, or other wastes; surplus or banned pesticides or other chemicals; polluted soils; and drums containing hazardous materials from removal actions or accidental releases. Disposal may be accomplished through use of approved secure landfills, surface impoundments, land farming, deep-well injection, ocean dumping, or incineration

**disposal facilities** repositories for solid waste, including landfills and combustors intended for permanent containment or destruction of waste materials. Excludes transfer stations and composting facilities

**disseminated ore deposit** a large, low-grade ore deposit in which generally fine-grained metal-bearing minerals are widely scattered throughout a rock body is sufficient concentration to make the deposit economical to mine

**dissolved load** the portion of a stream's sediment load that is carried in solution

**dissolved oxygen (DO)** the available oxygen in water, vital to fish and other aquatic life and for the prevention of odors. DO levels are considered an important indicator of a water body's ability to support desirable aquatic life. Secondary and advanced waste treatments are generally designed to ensure adequate DO in waste-receiving waters

**dissolved solids** disintegrated organic and inorganic material in water. Excessive amounts make water unfit to drink or use in industrial processes

**distillation** the act of purifying liquids through boiling, so that the steam or gaseous vapors condense to a pure liquid. Pollutants and contaminants may remain in the concentrated, undistilled residue

**disturbance** any event or series of events that disrupt ecosystem, community, or population structure and alter the physical environment

**diversion** use of part of a stream as a water supply. Also, a channel with a supporting ridge on the lower side constructed across a slope to divert water at a nonerosive velocity to sites where it can be used and disposed of

**diversion rate** the percentage of waste materials diverted from traditional disposal such as land-filling or incineration to be recycled, composted, or reused

**DNA (deoxyribonucleic acid)** a large organic molecule inside the chromosomes of the cell that stores genetic information. Responsible for passing biological traits from parents to offspring

**DNA hybridization** use of a segment of DNA, called a DNA probe, to identify its complementary DNA; used to detect specific genes

**DNAPL (dense nonaqueous phase liquid)** non-aqueous phase liquids such as chlorinated hydrocarbon solvents or petroleum fractions with a specific gravity greater than 1.0 sink through the water column until they reach a confining layer. They settle at the bottom of aquifers instead of floating on the water table, and typical monitoring wells do not indicate their presence. Cleanup of DNAPL is much more difficult

**Dobson unit (DU)** units of ozone level measurement. If, for example, 100 DU of ozone were taken to the Earth's surface, it would form a layer 0.04 inch (1 mm) thick

**domestic application** pesticide application in and around houses, office buildings, motels, and other living or working areas

**dosage/dose** the actual quantity of a chemical administered to an organism or to which it is exposed. Also, the amount of a substance that reaches a specific tissue (e.g., the liver). It also can mean the amount of a substance available for interaction with metabolic processes after crossing the outer boundary of an organism

**dose equivalent** the measure of an absorbed dose of ionizing radiation in an organism that accounts for biological differences, the type of radiation, and its distribution in the body

**dose rate** in exposure assessment, dose per time unit (e.g., mg/day). Also called dosage

**dose-response assessment** the estimate of the potency of a chemical. In exposure assessment, the process of determining the relationship between the dose of a stressor and a specific biological response. Also, evaluating the quantitative relationship between dose and toxicological responses

**dose-response curve** graphical representation of the relationship between the dose of an environmental stressor and the associated biological response (e.g., number of cigarettes smoked and the incidence of lung cancer)

**dose-response relationship** the quantitative relationship between the amount of exposure to a substance and the extent of toxic injury or disease it produces

**dosimeter** an instrument to measure dosage. Many so-called dosimeters actually measure exposure rather than dosage. Dosimetry is the

process or technology of measuring and/or estimating dosage

**DOT reportable quantity** the quantity of a hazardous or dangerous substance specified in a U.S. Department of Transportation regulation that triggers labeling, packaging, and other requirements related to shipping such substances

**downgradient** the direction that groundwater flows. Similar to *downstream* for surface water

**DP hole** hole in the ground made with direct push (DP) equipment

**draft permit** a preliminary permit drafted and published by EPA. It is subject to public review and comment before final action on the application

**drainage** improving the productivity of agricultural land by removing excess water from the soil by such means as ditches or subsurface drainage tiles

**drainage basin** the area of land that drains surface water, groundwater, sediment, and dissolved materials to a common stream channel

**drainage well** a well drilled to carry excess water off agricultural fields. Drainage wells act as a funnel from the surface to the groundwater below, where they can contribute to groundwater pollution

**drawdown** the drop in the water table or level of water in the ground when water is being pumped from a well. The amount of water used from a tank or reservoir. It also refers to the drop in the water level of a tank or reservoir

**dredging** removal of mud, silt, and other materials from the bottom of water bodies. This can disturb the ecosystem and cause increased turbidity that destroys aquatic life. Dredging of contaminated materials can expose biota to heavy metals and other toxics. Dredging activities may be subject to regulation under Section 404 of the Clean Water Act

**drilling fluid** fluid used to lubricate the bit and convey drill cuttings to the surface with rotary drilling equipment. Usually composed of bentonite slurry or muddy water. Can become contaminated and may require special disposal

**drinking water equivalent level** protective level of exposure related to potentially noncarcinogenic effects of chemicals that are also known to cause cancer

**drinking water state revolving fund** the fund provides capitalization grants to states to develop drinking water revolving loan funds to help finance system infrastructure improvements, assure source-water protection, enhance

operation and management of drinking-water systems, and otherwise promote local water-system compliance and protection of public health

**drive casing** heavy-duty steel casing driven along with the sampling tool in cased direct push (DP) systems. Keeps the borehole open between sampling tool runs and is not removed until last sample has been collected

**drop-off** recyclable materials collection method in which individuals take them to a designated collection site

**dual-phase extraction** active withdrawal of both liquid and gas phases from a well, usually involving the use of a vacuum pump

**dump** a site used to dispose of solid waste without environmental controls

**duplicate** a second sample that is treated the same way as the original sample in order to determine the precision of the analytical method

**dustfall jar** an open container used to collect large particles from the air for measurement and analysis

**dynamometer** a device used to place a load on an engine and measure its performance

**dystrophic lakes** acidic, shallow bodies of water that contain much humus and/or other organic matter; contain many plants but few fish

**Earth Day** an annual worldwide celebration in April showing support for environmental protection

**ecological entity** in ecological risk assessment, a general term referring to a species, a group of species, an ecosystem function or characteristic, or a specific habitat or biome

**ecological exposure** exposure of a nonhuman organism to a stressor

**ecological impact** the effect of an artificial or natural activity on living organisms and their nonliving (abiotic) environment

**ecological indicator** a biotic or abiotic characteristic of an ecosystem that can be measured and that directly reflects integrity and sustainability of the system

**ecological integrity** a living system exhibits its integrity if, when subjected to disturbance, it corrects itself to a sustainable biomass end state. End states other than that which occurs in nature may be satisfactory

**ecological risk assessment** the assessment of the effects of human actions on a natural resource and the significance of those effects. Such analysis includes initial hazard identification, exposure and dose-response assessments, and risk characterization

**ecological sustainability or environmental sustainability** maintenance of ecosystem components and functions for future generations

**ecology** the relationship of living things to each other and their environment, or the study of such relationships

**economic poisons** chemicals used to control pests and to defoliate cash crops such as cotton

**ecosphere** the “biobubble” that contains life on Earth, in surface waters, and in the air

**ecosystem** the interacting system of a biological community and its nonliving environmental surroundings

**ecosystem structure** the relationship of the attributes of an ecosystem such as species population density, species richness or distribution, and standing crop biomass

**ecotone** a habitat created by the juxtaposition of distinctly different habitats; an edge habitat; or an ecological zone or boundary where two or more ecosystems meet

**effluent** wastewater—treated or untreated—that flows out of a treatment plant, sewer, or industrial outfall (pipe). Generally refers to wastes discharged into surface waters

**effluent guidelines** technical EPA documents that set effluent limitations for given industries and pollutants

**effluent limitation** restrictions established by a state or the EPA on quantities, rates, and concentrations of contaminants in wastewater discharges

**effusion** the passage of a gas through a small hole into an evacuated space

**ejector** a device used to disperse a chemical solution into water being treated

**electrochemistry** the study of the relationship between chemical reactions and electrical charges

**electrodialysis** a process that uses electrical current applied to permeable membranes to remove minerals from water. Often used to desalinate salty or brackish water

**electrolyte** a substance that separates into ions when it dissolves in water

**electromagnetic spectrum** the entire range of electromagnetic radiation from very long-wavelength, low-frequency radiation to very short-wavelength, high-frequency radiation. It includes X-rays, ultraviolet radiation, visible light, and infrared radiation, among others

**electron capture** a mode of radioactive decay for some unstable nuclides in which the nucleus captures an electron and converts a proton into a neutron. It can be used as an analytical tool or

an add-on to improve precision, especially with a gas chromatograph (GC)

**electroplating** the electrolytic deposition of a thin, uniform metal film on the surface of an object

**electrostatic precipitator (ESP)** a device that removes particles from a gas stream (smoke) after combustion occurs. The ESP imparts an electrical charge to the particles, causing them to adhere to metal plates inside the precipitator. Rapping on the plates causes the particles to fall into a hopper for disposal

**element** the basic form of a chemical species uniquely defined by its nuclear and electron configuration

**emergency (chemical)** a situation created by an accidental release or spill of hazardous chemicals that poses a threat to the safety of workers, residents, the environment, or property

**emergency and hazardous chemical inventory** a mandatory annual report that must be prepared by facilities having one or more extremely hazardous substances or hazardous chemicals above certain weight limits

**emergency exemption** provision in FIFRA under which EPA can grant temporary exemption to a state or another federal agency to allow the use of a pesticide product not registered for that particular use. Such actions involve unanticipated and/or severe pest problems where there is not time or interest by a manufacturer to register the product for that use

**emergency removal action** steps taken to remove contaminated materials that pose an imminent threat to local residents (e.g., removal of leaking drums or excavation of explosive waste)

**emergency response values** concentrations of chemicals, published by various scientific and governmental groups, defining acceptable levels for short-term exposures in emergencies

**emergency suspension** suspension of a pesticide product registration due to an imminent hazard. The action immediately halts distribution, sale, and sometimes actual use of the pesticide involved

**emergent coastline** a coastline that recently was underwater but has now been exposed because the land has risen or sea level has fallen

**emission** pollution discharged into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities; from residential chimneys; and from motor vehicle, locomotive, or aircraft exhausts

**emission cap** a limit designed to prevent projected growth in emissions from existing and future stationary sources that erode any mandated reductions. Generally, such provisions require that any emission growth from facilities under the restrictions must be offset by equivalent reductions at other facilities under the same cap

**emission factor** the relationship between the amount of pollution produced and the amount of raw material processed. For example, an emission factor for a blast furnace making iron would be the number of pounds (kilograms) of particulates per ton (metric ton) of raw materials

**emission inventory** a listing, by source, of the amount of air pollutants discharged into the atmosphere of a community. Used to establish emission standards

**emission standard** the maximal amount of air polluting discharge legally allowed from a single source, mobile or stationary

**emissions trading** the creation of surplus emission reductions at certain stacks, vents, or similar emission sources and the use of this surplus to meet or redefine pollution requirements applicable to other emissions sources. This allows one source to increase emissions when another source reduces them, maintaining an overall constant emission level. Facilities that reduce emissions substantially may “bank” their “credits” or sell them to other facilities or industries

**emulsifier** a chemical that aids in suspending one liquid in another. Usually an organic chemical in an aqueous solution

**encapsulation** the treatment of asbestos-containing material with a liquid that covers the surface with a protective coating or embeds fibers in an adhesive matrix to prevent their release into the air

**enclosure** the installation of an airtight, impermeable, permanent barrier around asbestos-containing materials to prevent the release of asbestos fibers into the air

**endangered species** animals, birds, fish, plants, or other living organisms threatened with extinction by human activities or other natural changes in their environment. Requirements for declaring a species endangered are contained in the Endangered Species Act

**endangerment assessment** a study to determine the nature and extent of contamination at a site on the National Priorities List and the risks posed to public health or the environment. The EPA or the state conducts the study when a legal

action is to be taken to direct potentially responsible parties (PRPs) to clean up a site or pay for such a cleanup. An endangerment assessment supplements a remedial investigation

**end-of-the-pipe** technologies such as scrubbers on smokestacks and catalytic converters on automobile tailpipes that reduce emissions of pollutants after they have formed

**endothermic reaction** a reaction that absorbs heat from the surroundings

**end-use product** a pesticide formulation for field or other end use. The label has instructions for use or application to control pests or regulate plant growth. The term excludes products used to formulate other pesticide products

**energy recovery** obtaining energy from waste through a variety of processes (e.g., combustion)

**energy resources** geologic resources, including coal, petroleum, natural gas, and nuclear fuel, used for light, heat, and power

**enforcement** EPA, state, or local legal actions to obtain compliance with environmental laws, rules, regulations, or agreements and/or obtain penalties or criminal sanctions for violations. Enforcement procedures may vary, depending upon the requirements of environmental laws and related implementing regulations. Under CERCLA, for example, the EPA will seek to require potentially responsible parties (PRPs) to clean up a Superfund site or pay for the cleanup, whereas under the Clean Air Act the agency may invoke sanctions against cities failing to meet ambient air quality standards that could prevent certain types of construction or federal funding. In other situations, if investigations by the EPA and state agencies uncover willful violations, criminal trials and penalties are sought

**Enforcement Decision Document (EDD)** a document that provides an explanation to the public of EPA's selection of the cleanup alternative at enforcement sites on the National Priorities List. Similar to a Record of Decision (ROD)

**engineered controls** method of managing environmental and health risks by placing a barrier between the contamination and the rest of the site, thus limiting exposure pathways

**enrichment** the addition of nutrients (e.g., nitrogen, phosphorus, carbon compounds) from sewage effluent or agricultural runoff to surface water. It greatly increases the growth potential for algae and other aquatic plants

**entrain** to trap bubbles in water either mechanically through turbulence or chemically through a reaction



**environmental assessment** an environmental analysis prepared following the guidelines of the National Environmental Policy Act to determine whether a federal action would significantly affect the environment and thus require a more detailed Environmental Impact Statement

**environmental audit** an independent assessment of the current status of a party's compliance with applicable environmental requirements or of a party's environmental compliance policies, practices, and controls

**environmental exposure** human exposure to pollutants originating from facility emissions. Threshold levels are not necessarily surpassed, but low-level chronic pollutant exposure is one of the most common forms of environmental exposure

**environmental fate** the destiny of a chemical or biological pollutant after release into the environment

**environmental fate data** data that characterize a pesticide's fate in the ecosystem, considering factors that foster its degradation (light, water, microbes), pathways, and resultant breakdown products

**Environmental Impact Statement (EIS)** a document required of federal agencies by the National Environmental Policy Act for major projects or legislative proposals that significantly affect the environment. A tool for decision making, it describes the positive and negative effects of the undertaking and explains alternative actions

**environmental indicator** a measurement, statistic, or value that provides a proximate gauge or evidence of the effects of environmental management programs or of the state or condition of the environment

**environmental justice (EJ, environmental equity)** equal protection from environmental hazards for individuals, groups, or communities regardless of race, ethnicity, or economic status. This applies to the development, implementation, and enforcement of environmental laws, regulations, and policies and implies that no population of people should be forced to shoulder a disproportionate share of negative environmental impacts of pollution or environmental hazard because of lack of political or economic influence. The fair treatment of people of all races, cultures, incomes, and educational levels with respect to the development and enforcement of environmental laws, regulations, and policies

**environmental lien** a charge, security, or encumbrance on a property's title to secure payment of cost or debt arising from response actions, cleanup, or other remediation of hazardous substances or petroleum products

**environmental medium** an environmental system (e.g., surface water, groundwater, soil, or air) that surrounds or contacts humans, animals, plants, and other organisms and through which chemicals or pollutants move

**environmental response team** EPA experts located in Edison, New Jersey, and Cincinnati, Ohio, who can provide around-the-clock technical assistance to EPA regional offices and states during all types of hazardous waste site emergencies and spills of hazardous substances

**environmental risk or ecological risk** the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources

**environmental site assessment** the process of determining whether contamination is present on a parcel of real estate as well as its condition

**environmental sustainability** long-term maintenance of ecosystem components and functions for future generations

**enzyme** a biological compound that catalyzes a specific biochemical reaction

**epicenter** the point on the Earth's surface directly above the focus of an earthquake

**epilimnion** upper waters of a thermally stratified lake affected by wind action

**episode (pollution)** an air pollution incident in a given area caused by a concentration of atmospheric pollutants under meteorological conditions that may result in a significant increase in illnesses or deaths. May also describe water pollution events or hazardous material spills

**equilibrium** in relation to radiation, the state at which the radioactivity of consecutive elements within a radioactive series is neither increasing nor decreasing. In chemistry, a state in which the tendency of reactants to form products is balanced by the tendency of products to form reactants

**equivalent method** any method of sampling and analyzing for air, water, or soil pollution that has been demonstrated to the EPA administrator's satisfaction to be, under specific conditions, an acceptable alternative to normally used reference methods

**erosion** the wearing away of land surface by wind, water, or ice, intensified by land-clearing prac-

- tices related to farming, residential or industrial development, roadbuilding, or logging
- error** the difference between the measured result and the true value
- estuary** region of interaction between rivers and near-shore ocean waters, where tidal action and river flow mix freshwater and salt water. Such areas include bays, mouths of rivers, salt marshes, and lagoons. These brackish water ecosystems shelter and feed marine life, birds, and wildlife
- ethanol** an alternative automotive fuel derived from grain and corn; usually blended with gasoline to form gasohol
- eustatic sea level change** a global change in sea level. Causes include the growth or melting of glaciers and variations in water temperature
- eutrophic lakes** shallow, murky bodies of water with concentrations of plant nutrients causing excessive production of algae
- evaporation** the change of molecules from the liquid phase into the gas phase
- evaporation ponds** areas where sewage sludge is spread out and dried
- exceedance** violation of the pollutant levels permitted by environmental protection standards
- exclusionary ordinance** zoning that excludes classes of persons or businesses from a particular neighborhood or area
- exempted aquifer** underground water-carrying bodies defined in the Underground Injection Control program as aquifers that are potential sources of drinking water though not being used as such and, thus, exempted from regulations barring underground injection activities
- exemption** a state (with primacy) may exempt a public water system from a requirement involving a maximum contaminant level (MCL), treatment technique, or both, if the system cannot comply as a result of compelling economic or other factors, or because the system was in operation before the requirement or MCL was instituted; and the exemption will not create a public health risk
- exempt solvent** specific organic compounds not subject to requirements of regulation because they are deemed by EPA to be of negligible photochemical reactivity
- exothermic reaction** a reaction that releases heat to the surroundings
- exotic species** a species that is not indigenous to a region
- experimental use permit** obtained by manufacturers for testing new pesticides or new uses for existing pesticides. Required whenever they conduct experimental field studies to support registration on 10 acres (4.05 ha) or more of land or one acre (0.4 ha) or more of water
- explosive limits** the amounts of vapor in the air that form explosive mixtures; limits are expressed as lower and upper limits and give the range of vapor concentrations in air that will explode if an ignition source is present
- exports** in solid waste programs, municipal solid waste and recyclables transported outside the state or locality where they originated
- exposure** the amount of radiation or pollutant present in a given environment that represents a potential health threat to living organisms
- exposure assessment** identifying the pathways by which toxicants may reach individuals, estimating how much of a chemical an individual is likely to be exposed to, and estimating the number of individuals likely to be exposed
- exposure concentration** the concentration of a chemical or other pollutant representing a health threat in a given environment
- exposure indicator** a characteristic of the environment measured to provide evidence of the occurrence or magnitude of a response indicator's exposure to a chemical or biological stress
- exposure level** the amount (concentration) of a chemical at the absorptive surfaces of an organism
- exposure pathway** the path from sources of pollutants via soil, water, or food to humans and other species or settings
- exposure-response relationship** the relationship between exposure level and the incidence (occurrence) of adverse effects
- exposure route** the way a chemical or pollutant enters an organism after contact (i.e., by ingestion, inhalation, or dermal absorption)
- extensive properties (of matter)** those that depend upon the specific sample that is under observation (e.g., weight, volume)
- externalities** the direct and indirect costs associated with living in a degraded environment. Includes increased medical costs, lowered land values, higher energy costs, and so on
- extraction procedure (EP Toxic)** determining toxicity by a procedure that simulates leaching; if a certain concentration of a toxic substance can be leached from a waste, that waste is considered hazardous (i.e., EP Toxic)
- extraction well** a well used to remove and discharge groundwater or air to a treatment process or the environment

**extremely hazardous substances** any of 406 chemicals identified by EPA as toxic and listed under SARA Title III. The list is subject to periodic revision

**fabric filter** a cloth device that catches dust particles from industrial emissions, usually used in a baghouse See BAGHOUSE FILTER

**facultative bacteria** bacteria that can live under aerobic or anaerobic conditions

**fault** a fracture in rock along which movement has occurred. Faults generate earthquakes

**feasibility study** analysis of the practicability of a proposal. A description and analysis of potential cleanup methods for a polluted site such as one on the National Priorities List. The feasibility study usually recommends selection of a cost-effective alternative and starts as soon as the remedial investigation (RI) is under way. Together, both processes commonly are referred to as the "RI/FS"

**fecal coliform bacteria** bacteria found in the intestinal tracts of mammals. Their presence in water or sludge is an indicator of pollution and possible contamination by pathogens

**Federal Implementation Plan** under current law, a federally implemented plan to achieve attainment of air quality standards, used when a state is unable to develop an adequate plan

**Federal Motor Vehicle Control Program** all federal actions aimed at controlling pollution from motor vehicles by such efforts as establishing and enforcing tailpipe and evaporative emission standards for new vehicles, testing methods development, and guidance to states operating inspection and maintenance programs

**feedlot** a confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by storm-water runoff

**fen** a type of wetland that accumulates peat deposits. Fens are less acidic than bogs, deriving most of their water from groundwater rich in calcium and magnesium

**ferrous metals** metals that include a component of iron such as steel, pig iron, and alloys that contain iron. Products made from ferrous metals include appliances, furniture, containers, and packaging such as steel drums and barrels. Recycled products include processing tin/steel cans, strapping, and metals from appliances into new products

**FIFRA pesticide ingredient** an ingredient of a pesticide that must be registered with EPA under the Federal Insecticide, Fungicide, and Rodenti-

cide Act. Products making pesticide claims must register under FIFRA and may be subject to labeling requirements and use restrictions

**fill** synthetic deposits of natural soils or a combination of natural soils, rocks, rock products, and waste materials

**filling** depositing soil, mud, or other materials into aquatic areas to create dry land, usually for agricultural or commercial development purposes. Filling often destroys the indigenous ecological resources of the area being developed

**filter strip** narrow elongated region, strip, or area of vegetation used for removing sediment, organic matter, and other pollutants from runoff and wastewater

**filtration** a treatment process, under the control of qualified operators, for removing solid (particulate) matter from water by means of porous media such as sand or a synthetic filter; often used to remove particles that contain pathogens

**Financial Assurance for Closure** documentation or proof that an owner or operator of a facility such as a landfill or other waste repository is capable of paying the projected costs associated with closing the facility and monitoring it afterward as provided in RCRA regulations

**Finding of No Significant Impact (FoNSI)** a document prepared by a federal agency showing why a proposed action would not have a significant impact on the environment and, thus, would not require preparation of an Environmental Impact Statement. A FoNSI is based on the results of an environmental assessment

**finished water** potable water that has passed through all the processes in a water treatment plant and is ready to be delivered to consumers

**first draw** potable water that flows out when a tap is first opened, likely to have the highest level of lead contamination from plumbing materials

**fission** the breakdown of an atomic nucleus of an element of relatively high atomic number into two or more nuclei of lower atomic number, with conversion of part of the mass to energy

**fix a sample** addition of chemicals to a sample that prevents water quality indicators of interest in the sample from changing before laboratory measurements are made

**fixed-location monitoring** sampling of an environmental or ambient medium (air or water) for pollutant concentration at one location continuously or repeatedly

**flammable** any material that ignites easily and burns rapidly

**flare** a control device that ignites and burns hazardous materials to prevent their release into the

environment; may operate continuously or intermittently, usually on top of a stack

**flash point** the lowest temperature at which evaporation of a substance produces sufficient vapor to form an ignitable mixture with air

**floc** a clump of solids formed in sewage by biological or chemical action

**flocculation** process by which clumps of solids in water or sewage aggregate through biological or chemical action so they can be separated from water or sewage

**floodplain** the flat or nearly flat land along a river or stream or in a tidal area that is covered by water during a flood

**floor sweep** capture of heavier-than-air gases that collect at floor level

**flowable** pesticide and other formulations in which the active ingredients are finely ground insoluble solids suspended in a liquid. They are mixed with water for application

**flowmeter** a gauge or instrument that measures the velocity of wastewater moving through a treatment plant or of any liquid moving through various industrial processes

**flow rate** the rate at which a medium flows. In environmental work, it is the rate at which a fluid escapes from a hole or fissure in a tank in gallons or liters per hour. Such measurements also are made of liquid waste, effluent, and surface water movement

**flue gas** the exhaust out of a chimney after combustion in the burner it is venting. It can include nitrogen oxides, carbon oxides, water vapor, sulfur oxides, particles, and many other chemical pollutants

**flue gas desulfurization** a technology that employs a material, usually lime or limestone, to remove sulfur dioxide chemically from the gases produced by burning fossil fuels. Flue gas desulfurization is current state-of-the-art technology for major SO<sub>2</sub> emitters, such as power plants

**fluidized** a mass of solid particles that is made to flow as a liquid by injection of water or gas. In water treatment, a bed of filter medium is fluidized by backwashing water through the filter

**fluidized bed incinerator** an incinerator that uses a bed of hot sand or other granular material to transfer heat directly to waste. Used mainly for destroying municipal sludge

**flume** a natural or synthetic channel that diverts water

**fluoridation** the addition of a chemical to increase the concentration of fluoride ions in drinking water to reduce the incidence of tooth decay

**fluorides** gaseous, solid, or dissolved compounds containing fluorine that result from industrial processes. Excessive amounts in food can lead to fluorosis

**fluorocarbons (FCs)** any of a number of organic compounds analogous to hydrocarbons in which one or more hydrogen atoms are replaced by fluorine. Once used in the United States as a propellant for domestic aerosols, they are now found mainly in coolants and some industrial processes. FCs containing chlorine are called chlorofluorocarbons (CFCs). They are believed to be modifying the ozone layer in the stratosphere, thereby allowing harmful ultraviolet radiation to reach the Earth's surface

**flush** to open a cold-water tap to clear out all the water that may have been sitting for a long time in the pipes. In new homes, to flush a system means to send large volumes of water gushing through the unused pipes to remove loose particles of solder and flux. Also, to force large amounts of water through a system to clean out piping or tubing, storage or process tanks

**fly ash** noncombustible (i.e., mineral) residual particles expelled by flue gas. Eventually fly ash settles to the ground as a gritty dust

**focus** the belowground, rupture point of a fault that produces an earthquake

**fog** a cloud that forms at or very close to ground level

**fogging** applying a pesticide by rapidly heating the liquid chemical so that it forms very fine droplets that resemble smoke or fog. Used to destroy mosquitoes, black flies, and similar pests

**food chain** a sequence of organisms, each of which uses the next, lower member of the sequence as a food source

**food processing waste** food residues produced during agricultural and industrial operations

**food waste** uneaten food and food preparation wastes from residences and commercial establishments such as grocery stores, restaurants, and produce stands; institutional cafeterias and kitchens; and industrial sources such as employee lunchrooms

**food web** the feeding relationships by which energy and nutrients are transferred from one species to another

**formulation** the substances composing all active and inert ingredients in a pesticide

**fossil fuel** fuel derived from the remains of ancient organisms (e.g., peat, coal, crude oil, and natural gas)

**fracture** a break in a rock caused by structural stresses (e.g., faults, joints, and planes of fracture cleavage)



- freeboard** vertical distance from the usual water surface to the top of a confining wall. Also, the vertical distance from the sand surface to the underside of a trough in a sand filter
- free product** a petroleum hydrocarbon in the liquid-free or nonaqueous phase
- frequency** the number of complete wave cycles, from crest to crest, that pass by any given point in a second
- freshwater** water that generally contains less than 1,000 milligrams per liter of dissolved solids
- friable** capable of being crumbled, pulverized, or reduced to powder by hand pressure
- friable asbestos** any material containing more than 1 percent asbestos that can be crumbled or reduced to powder by hand pressure. May include previously nonfriable material that is broken or damaged by mechanical force
- fuel efficiency** the proportion of energy released by fuel combustion that is converted into useful energy
- fuel rod** a 6.56-foot (2-m) column of uranium pellets used as the fission source in a nuclear reactor
- fuel switching** a precombustion process whereby a low-sulfur coal is used in place of a higher-sulfur coal in a power plant to reduce sulfur dioxide emissions. Also, illegally using leaded gasoline in a motor vehicle designed to use only unleaded
- fugitive emissions** emissions not caught by a capture system
- fume** tiny particles trapped in vapor in a gas stream
- fumigant** a pesticide vaporized to kill pests. Used in buildings and greenhouses
- functional equivalent** term used to describe EPA's decision-making process and its relationship to the environmental review conducted under the National Environmental Policy Act (NEPA). A review is considered functionally equivalent when it addresses the substantive components of NEPA
- functional group** an atom or small group of atoms in a molecule that undergo characteristic reactions
- fungicide** pesticide that is used to control, deter, or destroy fungi
- fungistat** a chemical that prevents fungi from growing
- fungus (fungi)** molds, mildews, yeasts, mushrooms, and puffballs, a group of organisms lacking chlorophyll (i.e., not photosynthetic), which usually are nonmobile, filamentous, and multicellular. Some grow in soil; others attach themselves to decaying trees and plants, whence they obtain nutrients. Some are pathogens; others stabilize sewage and digest composted waste
- furrow irrigation** irrigation method in which water travels through the field by means of small channels between groups of rows
- fusion** the combination of nuclei of light elements (particularly hydrogen) to form heavier nuclei. This process results in the release of energy (i.e., heat)
- future liability** refers to potentially responsible parties' obligations to pay for additional response activities beyond those specified in the Record of Decision or Consent Decree
- Gaia hypothesis** concept that Earth behaves as a single self-sustaining and self-regulating system or super-organism and that living things interact in a way that stabilizes the climate and allows life to flourish
- garbage** animal and vegetable waste resulting from the handling, storage, sale, preparation, cooking, and serving of foods
- gasahol** mixture of gasoline and ethanol derived from fermented agricultural products containing at least 9 percent ethanol. Gasahol emissions contain less carbon monoxide than those from gasoline
- gas chromatograph/mass spectrometer (GC/MS)** instrument that identifies the molecular composition and concentrations of trace amounts of elements in organic chemicals in water and soil samples
- gasification** conversion of solid material such as coal into a gas for use as a fuel
- gasoline volatility** the property of gasoline whereby it evaporates into a vapor. Gasoline vapor is a mixture of volatile organic compounds (VOCs)
- generally recognized as safe (GRAS)** designation by the Food and Drug Administration that a chemical or substance (including certain pesticides) added to food is considered safe by experts and so is exempted from food additive limits
- generator** a facility or mobile source that emits pollutants into the air or releases hazardous waste into water or soil. Also, any person (by site) whose act or process produces regulated medical waste or whose act first causes such waste to become subject to regulation
- genetic engineering** a process of inserting new genetic information into existing cells in order to modify a specific organism for the purpose of changing one of its characteristics
- genotoxic** damaging to deoxyribonucleic acid (DNA) or pertaining to agents known to damage DNA
- Geographic Information System (GIS)** a computer system designed for storing, manipulating,

- analyzing, and displaying data in a geographic context. A spatial database management system
- geologic column** a composite diagram that shows the sequence of rocks at a given place or region arranged to show their position and ages. A stratigraphic column
- geologic log** a detailed description of all underground soil and rock features (depth, thickness, type of formation) encountered during the drilling of a well
- geosphere** the Earth from its center (core) to outer crust
- geothermal energy** energy derived from the heat of the Earth
- geothermal gradient** the rate at which temperature increases with depth below ground surface
- geothermal/ground source heat pump** underground coils used to transfer heat from the ground to the inside of a building
- germicide** any compound that kills disease-causing microorganisms
- glass containers** for recycling purposes, containers such as bottles and jars for drinks, food, cosmetics, and other products. When being recycled, container glass is generally separated into color categories for conversion into new containers, construction materials, or fiberglass insulation
- Global Positioning System (GPS)** a system using satellite telemetry to determine the exact location of a receiver or GPS unit on the ground. The system determines latitude, longitude, and altitude by triangulation from multiple satellites
- global warming potential (GWP)** the ratio of the warming caused by a substance to the warming caused by a similar mass of carbon dioxide. CFC-12, for example, has a GWP of 8,500, whereas water has a GWP of 0
- glovebag** a polyethylene or polyvinyl chloride bag-like enclosure affixed around an asbestos-containing source (most often thermal system insulation) permitting the material to be removed while minimizing release of airborne fibers to the surrounding atmosphere
- gooseneck** a portion of a water service connection between the distribution system water main and a meter. Sometimes called a pigtail
- grab sample** a single sample collected at a particular time and place that represents the composition of the water, air, or soil only at that time and place
- graded stream** a stream with a concave profile that is in equilibrium with its sediment supply; it transports all the sediment supplied to it with neither erosion of nor deposition within the stream bed
- gradient** the vertical drop of water level over a given distance within a stream bed or aquifer
- granular activated carbon treatment (GAC)** a filtering system often used in low-flow water systems and individual homes to remove organics. Although expensive to use on a large scale, GAC can be highly effective in lowering elevated levels of organic chemicals and radon in water
- grassed waterway** natural or constructed watercourse or outlet that is shaped or graded and established in suitable vegetation for the disposal of runoff water without erosion
- gray water** domestic wastewater composed of wash water from kitchen, bathroom, and laundry sinks, tubs, and washers
- greenhouse effect** the warming of the Earth's atmosphere attributed to a buildup of carbon dioxide or other gases. This buildup allows the Sun's rays to heat the Earth, while reducing the ability of the atmosphere to dissipate reradiated energy associated with surface heating. Also, the effect of a blanket of gases that insulate the Earth and prevent it from radiating heat
- gross alpha or beta particle activity** the total radioactivity due to alpha or beta particle emissions as inferred from measurements on a dry sample
- ground cover** plants grown to prevent soil from eroding
- ground-penetrating radar (GPR)** a geophysical method that uses high-frequency electromagnetic waves to obtain subsurface information
- Ground-Water Disinfection Rule** a 1996 amendment of the Safe Drinking Water Act requiring EPA to promulgate national primary drinking water regulations requiring disinfection for all public water systems, including surface waters and groundwater systems
- gully erosion** severe erosion in which trenches are cut to a depth greater than one foot (30 cm). Generally, ditches deep enough to cross with farm equipment are considered gullies
- habitat** the place where a population (e.g., human, animal, plant, microorganism) lives and its surroundings, both living and nonliving
- habitat indicator** a physical attribute of the environment measured to characterize conditions necessary to support an organism, population, or community in the absence of pollutants
- half-life** the time required for a pollutant to lose one-half of its original concentration. For radioactive compounds, the time required for half of the atoms of a radioactive element to undergo decay
- halon** bromine-containing compounds with long atmospheric lifetimes whose breakdown in the

stratosphere causes depletion of ozone. Halons are used in firefighting

**hammer mill** a high-speed machine that uses hammers and cutters to crush, grind, chip, or shred solid waste

**hard water** alkaline water containing dissolved salts that interfere with some industrial processes and prevent soap from forming suds

**hazard** potential for radiation, chemical, or other pollutant to cause human illness or injury. Hazard identification of a given substance is based on verifiable toxicity data from animal models or human studies

**hazard assessment** evaluating the effects of a stressor or determining a margin of safety for an organism by comparing the concentration that causes toxic effects with an estimate of exposure to the organism

**Hazard Communication Standard** an OSHA regulation that requires chemical manufacturers, suppliers, and importers to assess the hazards of the chemicals they make, supply, or import and to inform employers, customers, and workers of these hazards through Material Safety Data Sheet information

**hazard evaluation** a component of risk evaluation that involves gathering and evaluating data on the types of health injuries or diseases that may be produced by a chemical and on the conditions of exposure under which such health effects are produced

**hazard identification** determining whether a chemical or a microbe can cause adverse health effects in humans and what those effects might be

**hazardous air pollutants** air pollutants that are not covered by ambient air quality standards but that, as defined in the Clean Air Act, may present a threat of adverse human health effects or adverse environmental effects. Such pollutants include asbestos, beryllium, mercury, benzene, coke oven emissions, radionuclides, and vinyl chloride

**Hazardous Chemical** an EPA designation for any hazardous material requiring an MSDS under OSHA's Hazard Communication Standard. Such substances are capable of producing fires and explosions or adverse health effects including cancer and dermatitis. Hazardous chemicals are distinct from HAZARDOUS WASTE.

**Hazardous Ranking System (HRS)** the principal screening tool used by EPA to evaluate risks to public health and the environment associated with abandoned or uncontrolled hazardous waste sites. The HRS calculates a score based on

the potential of hazardous substances to spread from the site through the air, surface water, or groundwater and on other factors such as density and proximity of human population. This score is the primary factor in deciding whether the site should be on the National Priorities List and, if so, what ranking it should have compared to other sites on the list

**hazardous substance** any material that poses a threat to human health and/or the environment. Typical hazardous substances are toxic, corrosive, ignitable, explosive, or chemically reactive. Also, any substance designated by EPA to be reported if a designated quantity of the substance is spilled into the waters of the United States or is otherwise released into the environment

**hazardous waste** by-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. Possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity) or appears on special EPA lists

**hazardous waste landfill** an excavated or engineered site where hazardous waste is disposed

**hazardous waste minimization** reducing the amount of toxicity or waste produced by a facility via source reduction or environmentally sound recycling

**hazard quotient** the ratio of estimated site-specific exposure to a single chemical from a site over a specified period to the estimated daily exposure level at which no adverse health effects are likely to occur

**hazard ratio** a term used to compare an animal's daily dietary intake of a pesticide to its LD50 value. A ratio greater than 1.0 indicates that the animal is likely to consume a dose that would kill 50 percent of animals of the same species

**hazards analysis** procedures used to identify potential sources of release of hazardous materials from fixed facilities or transportation accidents, to determine the vulnerability of a geographical area to a release of hazardous materials, and to compare hazards to determine which present greater or lesser risks to a community

**hazards identification** a process to provide information on the facilities that have extremely hazardous substances, what those substances are, how much there is at each facility, how the substances are stored, and whether they are used at high temperatures

**headspace** the vapor mixture trapped above a solid or liquid in a sealed vessel

**Health Advisory Level** a nonregulatory health-based reference level of chemical traces (usually in parts per million) in drinking water at which there are no adverse health risks when ingested over various periods. Such levels are established for one day, 10 days, long-term, and lifetime exposure periods. They contain a wide margin of safety

**Health Assessment** an evaluation of available data on existing or potential risks to human health posed by a Superfund site. The Agency for Toxic Substances and Disease Registry (ATSDR) of the Department of Health and Human Services (DHHS) is required to perform such an assessment at every site on the National Priorities List

**heat island effect** a “dome” of elevated temperatures over an urban area caused by structural and pavement heat fluxes and pollutant emissions

**heat pump** an electric device with both heating and cooling capabilities. It extracts heat from one medium at a lower temperature (the heat source) and transfers it to another at a higher temperature (the heat sink), thereby cooling the first and warming the second

**heavy metals** metallic elements with high atomic weights and inorganic pollutants (e.g. arsenic, cadmium, chromium, lead, mercury, and nickel) that can damage living organisms at low concentrations and tend to accumulate in the food chain

**herbicide** a chemical pesticide designed to control or destroy plants, weeds, or grasses

**herbivore** an animal that feeds on plants

**heterotrophic organisms** species dependent on organic matter for food

**high-density polyethylene (HDPE)** a material used to make plastic bottles and other products that produces toxic fumes when burned

**highest dose tested** the highest dose of a chemical or substance tested in a study

**high-level nuclear waste facility** plant designed to handle disposal of used nuclear fuel, high-level radioactive waste, and plutonium waste

**high-line jumpers** pipes or hoses connected to fire hydrants and placed on top of the ground to provide emergency water service for an isolated portion of a distribution system

**high-risk community** a community in the vicinity of numerous sites, facilities, or other potential sources of environmental pollution that may result in high levels of exposure

**high-to-low-dose extrapolation** the process of prediction of low exposure risk to humans and animals from the measured high-exposure-high-risk data involving laboratory animals

**holding pond** a pond or reservoir, usually made of earth, built to store polluted water

**holding time** the maximum amount of time a sample may be stored before analysis

**hollow stem auger drilling** conventional drilling method that uses augers to penetrate the soil. As the augers are rotated, soil cuttings are conveyed to the ground surface via spirals or flutes. Direct push (DP) tools can be used inside the hollow augers

**homeowner water system** any water system that supplies piped water to a single residence

**host** in genetics, the organism, typically a bacterium, into which a gene from another organism is transplanted. In medicine, an animal infected or parasitized by another organism

**household hazardous waste** hazardous products used and disposed of by residential as opposed to industrial consumers. Includes paints, stains, varnishes, solvents, pesticides, and other materials or products containing volatile chemicals that can catch fire, react, or explode or that are corrosive or toxic

**household waste (domestic waste)** solid waste composed of garbage and rubbish that normally originates in a private home or apartment house. Domestic waste may contain a significant amount of toxic or hazardous waste

**human equivalent dose** a dose that, when administered to humans, produces an effect equal to that produced by a dose in animals

**human exposure evaluation** describing the nature and size of the population exposed to a substance and the magnitude and duration of their exposure

**human health risk** the likelihood that a given exposure or series of exposures may have damaged or will damage the health of individuals

**humus** the dark organic component of soil composed of leaves, roots, and other debris that have sufficiently decomposed so that the origin of the individual pieces cannot be identified

**hydration** the chemical combination of water with another substance

**hydraulic action** the mechanical loosening and removal of material by flowing water

**hydraulic conductivity** the rate at which water can move through a permeable medium

**hydraulic gradient** in general, the direction of groundwater flow due to changes in the height of the water table

**hydride** a compound of hydrogen and one or more metals that can be heated to release hydrogen gas for use as a fuel

**hydrocarbon (HC)** chemical compound that consists entirely of carbon and hydrogen



**hydrogen economy** an economic system based on the use of hydrogen as the primary source of energy, rather than petroleum

**hydrogen sulfide (H<sub>2</sub>S)** gas emitted during organic decomposition. Also, a by-product of oil refining and burning. Has an odor similar to that of rotten eggs and, in heavy concentration, can kill or cause illness

**hydrogeology** the geology of groundwater, with particular emphasis on the chemistry and movement of water and the media that contain it

**hydrologic cycle (water cycle)** the natural process recycling water from the atmosphere to and through the surface of the Earth and back to the atmosphere again. Movement or exchange of water between the atmosphere and Earth

**hydrology** the science dealing with the properties, distribution, and circulation of water

**hydrolysis** the decomposition of organic compounds by interaction with water

**hydronic** a ventilation system using heated or cooled water pumped through a building

**hydrophilic** having a strong affinity (attraction) for water

**hydrophobic** having a strong aversion to (repulsion for) water

**hydropneumatic** a water system, usually small, in which a water pump is automatically controlled by the pressure in a compressed air tank

**hydrosphere** all of the Earth's water, including the atmosphere, oceans, and within the continents

**hygroscopic** a substance with the ability to absorb water vapor directly from the air

**hypersensitivity diseases** diseases characterized by allergic responses to pollutants; diseases most clearly associated with indoor air quality are asthma, rhinitis, and pneumonic hypersensitivity

**hypolimnion** bottom waters of a thermally stratified lake. The hypolimnion of a eutrophic lake is usually low or lacking in oxygen

**hypoxia/hypoxic waters** waters with dissolved oxygen concentrations of less than two parts per million, the level generally accepted as the minimum required for most marine life to survive and reproduce

**Identification Code or EPA I.D. number** the code assigned to each generator, transporter, and treatment, storage, or disposal facility by regulating agencies to identify and track chemicals and hazardous waste

**Imhoff cone** a clear, cone-shaped container used to measure the volume of settleable solids in a specific volume of water

**Immediately Dangerous to Life and Health (IDLH)** the maximal level to which a healthy individual can be exposed to a chemical for 30 minutes without irreversible health effects or impairing symptoms

**imminent hazard** one that would be likely to result in unreasonable adverse effects on humans or the environment or risk unreasonable hazard to an endangered species during the time required for a pesticide registration cancellation proceeding

**imminent threat** a high probability that exposure to a dangerous substance is occurring

**immiscibility** the inability of two or more substances or liquids, such as oil and water, to mix readily

**impermeable** the property of a material that does not allow, or allows only with great difficulty, the movement or passage of water or gas

**impoundment** a body of water or sludge confined by a dam, dike, floodgate, or other barrier

**incident command post** a facility located at a safe distance from an emergency site, where the incident commander, key staff, and technical representatives can make decisions and deploy emergency personnel and equipment

**incineration** destruction of waste by controlled burning at high temperatures. For example, burning sludge to evaporate the water and reduce the remaining residues to a nonburnable ash that can be disposed of safely on land, in some waters, or in underground locations

**incineration at sea** disposal of waste by burning at sea on specially designed incinerator ships

**incinerator** a furnace for burning waste under controlled conditions

**incompatible waste** a waste unsuitable for mixing with another waste or material because it may react to form a hazard

**indicator** in biology, any biological entity, processes, or community whose characteristics show the presence of specific environmental conditions. In chemistry, a substance that shows a visible change, usually of color, at a desired point in a chemical reaction. Also, a device that indicates the result of a measurement (e.g., a pressure gauge or a movable scale)

**indirect discharge** introduction of pollutants from a nondomestic source into a publicly owned waste-treatment system. Indirect dischargers can be commercial or industrial facilities whose wastes enter local sewers

**indirect source** any facility or building, property, road, or parking area that attracts motor vehicle traffic and, indirectly, causes pollution

- indoor air** the breathable air inside a habitable structure
- indoor climate** temperature, humidity, lighting, airflow, and noise levels in a habitable structure. Indoor climate can affect indoor air pollution
- industrial mineral** any rock or mineral of economic importance, exclusive of metal ores, fuels, and gems. Industrial minerals include abrasives, cement, clays, sand, gravel, asbestos, vermiculite, and many others
- industrial pollution prevention** combination of industrial source reduction and toxic chemical use substitution to reduce overall emissions
- industrial process waste** waste residues produced during manufacturing operations
- industrial sludge** semiliquid residue or slurry remaining after the treatment of industrial water and wastewater
- industrial source reduction** practices that reduce the amount of any hazardous substance, pollutant, or contaminant entering a waste stream or otherwise released into the environment. Also reduces the threat to public health and the environment associated with such releases. Term includes equipment or technology modifications, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control
- industrial waste** unwanted materials from an industrial operation; may be liquid, sludge, solid, or hazardous waste
- inertial separator** a device that uses centrifugal force to separate waste particles
- inert ingredient** pesticide components such as solvents, carriers, dispersants, and surfactants that are not active against target pests. Not all inert ingredients are innocuous
- infectious agent** any organism, such as a pathogenic virus, parasite, or bacterium, that is capable of invading body tissues, multiplying, and causing disease
- infectious waste** hazardous waste capable of causing infections in humans, including contaminated animal waste, human blood and blood products, isolation waste, pathological waste, and discarded sharp objects (needles, scalpels, or broken medical instruments)
- infiltration** the percolation of water through the ground surface into subsurface soil or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls. Also the treatment technique of applying large volumes of wastewater to land to penetrate the surface and percolate through the underlying soil
- infiltration gallery** a subsurface groundwater collection system, typically shallow in depth, with open-jointed or perforated pipes that discharge water into a watertight chamber from which it is pumped to treatment facilities and into the distribution system. Usually located close to streams or ponds
- infiltration rate** the quantity of water that can enter the soil in a specified time interval without ponding on the surface
- inflow** entry of extraneous rainwater into a sewer system from sources other than infiltration, such as basement drains, manholes, storm drains, and street washing
- influent** water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant
- information file** in the Superfund program, a file that contains accurate, up-to-date documents on a Superfund site. The file is usually located in a public building (school, library, or city hall) convenient for local residents
- injection well** a well into which fluids are injected for purposes such as waste disposal, improving the recovery of crude oil, or solution mining
- injection zone** a geological formation receiving fluids through a well
- in-line filtration** pretreatment method in which chemicals are mixed by flowing water. Most often used in pressure filtration installations. Eliminates need for flocculation and sedimentation
- inoculum** bacteria or fungi injected into compost to start biological action. Also, a medium containing organisms, usually bacteria or virus, that are introduced into cultures or living organisms
- insecticide** a pesticide compound specifically used to kill or prevent the growth of insects.
- in situ** in its original place; unmoved; unexcavated; remaining at the site or in the subsurface
- in situ flushing** introduction of large volumes of water, at times supplemented with detergents or other cleaning compounds, into soil, waste, or groundwater to flush hazardous contaminants
- in situ (chemical) oxidation (ISCO)** technology that oxidizes contaminants dissolved in groundwater, converting them into insoluble compounds
- in situ stripping** treatment system that removes, or strips, volatile organic compounds from contaminated ground or surface water by forcing an airstream through the water and causing the compounds to evaporate

**in situ vitrification** technology that treats contaminated soil in place at extremely high temperatures, greater than 3,000°F (1,650°C)

**institutional waste** waste generated at institutions such as schools, libraries, hospitals, and prisons

**instream use** water use within a stream channel (e.g., hydroelectric power generation, navigation, water quality improvement, fish propagation, recreation)

**integrated exposure assessment** cumulative summation (over time) of the magnitude of exposure to a toxic chemical in all media

**Integrated Pest Management (IPM)** a mixture of chemical- and non-chemical-based methods to control pests

**integrated waste management** using a variety of practices to handle municipal solid waste; can include source reduction, recycling, incineration, and landfilling.

**intensity** a measure of the effects of an earthquake on buildings and other structures at a specified location

**interceptor sewers** large sewer lines that, in a combined system, control the flow of sewage to the treatment plant. In a storm, they allow some of the sewage to flow directly into a receiving stream, thus preventing it from overflowing onto the streets. Also used in separate systems to collect the flows from main and trunk sewers and carry them to treatment points

**Interim (Permit) Status** period during which treatment, storage, and disposal facilities under RCRA jurisdiction since 1980 are temporarily permitted to operate while awaiting a permanent permit. Permits issued under these circumstances are usually called Part A or Part B permits

**intermediates** a compound that is produced in one step of the reaction and then consumed in a subsequent step. Intermediates are not present in either reactants or products

**internal dose** in exposure assessment, the amount of a substance penetrating the absorption barriers (e.g., skin, lung tissue, gastrointestinal tract) of an organism through either physical or biological processes

**interstate carrier water supply** a source of water for drinking and sanitary use on planes, buses, trains, and ships operating in more than one state. These sources are federally regulated

**Interstate Commerce clause** a clause of the U.S. Constitution that reserves to the federal government the right to regulate the conduct of

business across state lines. Under this clause, for example, the U.S. Supreme Court has ruled that states may not inequitably restrict the disposal of out-of-state wastes in their jurisdictions

**interstate waters** waters that flow across or form part of state or international boundaries (e.g., the Great Lakes, the Mississippi River, or coastal waters)

**interstitial monitoring** the continuous surveillance of the space between the walls of a double-walled underground storage tank

**in vitro** testing or action outside an organism (e.g., inside a test tube or culture dish)

**in vivo** testing or action inside an organism

**ion** an electrically charged atom or group of atoms

**ion exchange treatment** a common water-softening method often on a large scale at water purification plants to remove some organics and radium by adding calcium oxide or calcium hydroxide to increase the pH to a level where the metals precipitate

**ionization** the separation of a molecular compound into individual cations and anions that are dissolved in water

**ionization chamber** a device that measures the intensity of ionizing radiation

**ionizing radiation** radiation that can strip electrons from atoms (e.g. alpha, beta, and gamma radiation). Causes cellular damage

**IRIS** EPA's Integrated Risk Information System, an electronic database containing the agency's latest descriptive and quantitative regulatory information on chemical constituents

**irradiated food** food subject to brief radioactivity, usually gamma rays, to kill insects, bacteria, and mold and to permit storage without refrigeration

**irradiation** exposure to radiation of wavelengths shorter than those of visible light (gamma, X-ray, or ultraviolet), to perform medical procedures, to sterilize milk or other foodstuffs, or to induce polymerization of monomers or vulcanization of rubber

**irreversible effect** effect characterized by the inability of the body to repair injury caused by a toxic agent partially or fully

**irrigation** applying water or wastewater to land areas to supply the moisture and nutrient needs of plants

**irrigation efficiency** the amount of water stored in the crop root zone compared to the amount of irrigation water applied

**irrigation return flow** surface and subsurface water that leaves the field after application of irrigation water

- irritant** a substance that can cause irritation of the skin, eyes, or respiratory system. Effects may be acute from a single high-level exposure or chronic from repeated low-level exposures to such compounds as chlorine, nitrogen dioxide, and nitric acid
- isoconcentration** more than one sample point exhibiting the same concentration
- isomers** different compounds with the same molecular formula but with different structural formulas
- isopleth** the line made by connecting isoconcentration points
- isotope** a variation of an element that has the same atomic number of protons but a different atomic weight because of the number of neutrons. Various isotopes of the same element may have different radioactive behaviors; some are highly unstable
- isotropy** the condition in which the hydraulic or other properties of an aquifer are the same in all directions
- jar test** a laboratory procedure that simulates a water treatment plant's coagulation/flocculation units with differing chemical doses, mix speeds, and settling times to estimate the minimal or ideal coagulant dose required to achieve certain water quality goals
- joint and several liability** under CERCLA, this legal concept relates to the liability for Superfund site cleanup and other costs of more than one potentially responsible party (PRP) if there were several owners or users of a site that became contaminated over the years. They could all be considered potentially liable for site remediation
- kerogen** the material that yields oil when an oil shale is heated and distilled. It is a precursor of liquid petroleum
- kinetic rate coefficient** a number that describes the rate at which a water constituent such as a biochemical oxygen demand or dissolved oxygen rises or falls, or at which an air pollutant reacts
- Koeppen Climate System** a widely used climate classification system
- Kyoto Protocol** an 1997 international agreement drafted in Kyoto, Japan, whose goal was to reduce emission of six greenhouse gases to 1990 levels by the year 2012. The United States did not ratify this treaty
- lagoon** a shallow pond where sunlight, bacterial action, and oxygen work to purify wastewater; also used for storage of wastewater or spent nuclear fuel rods. In oceanography, a shallow body of water, often separated from the sea by coral reefs or sandbars
- land application** discharge of wastewater onto the ground for treatment or reuse
- Land Ban** phasing out of land disposal (burial) of most untreated hazardous wastes, as mandated by the 1984 RCRA amendments
- land disposal restrictions** rules that require hazardous wastes to be treated before disposal (burial) on land to destroy or immobilize hazardous constituents that might migrate into soil and groundwater
- land farming (of waste)** a disposal process in which hazardous waste deposited on or in the soil is degraded naturally by microbes
- landscape** the traits, patterns, and structure of a specific geographic area, including its biological composition, its physical environment, and its anthropogenic or social patterns
- landscape ecology** the study of the distribution patterns of communities and ecosystems, the ecological processes that affect those patterns, and changes in pattern and process over time
- landscape indicator** a measurement of the landscape, calculated from mapped or remotely sensed data, used to describe spatial patterns of land use and land cover across a geographic area. Landscape indicators may be useful as measures of certain kinds of environmental degradation such as forest fragmentation
- Langelier Index (LI)** an index reflecting the equilibrium pH of water with respect to calcium and alkalinity; used in stabilizing water to control both corrosion and scale deposition
- large quantity generator** person or facility generating more than 2,200 pounds (1,000 kg) of hazardous waste per month. Such generators produce about 90 percent of the nation's hazardous waste and are subject to all RCRA requirements
- large water system** a water system that serves more than 50,000 customers
- laser induced fluorescence** a method for measuring the relative amount of soil and/or groundwater with an in situ sensor
- latency** time from the first exposure of a chemical until the appearance of a toxic effect
- lateral sewers** pipes that lie under city streets and receive the sewage from homes and businesses, as opposed to domestic feeders and main trunk lines
- laundering weir** sedimentation basin or overflow weir
- LC50/lethal concentration** median level concentration, a standard measure of toxicity. It indicates how much of a substance is needed to kill



half of a group of experimental organisms in a given time

**LD50/lethal dose** the dose of a toxicant or microbe that will kill 50 percent of the test organisms within a designated period. The lower the LD50, the more toxic the compound

**ldlo** lethal dose low; the lowest dose in an animal study at which lethality occurs

**leachate collection system** a system that gathers leachate and pumps it to the surface for treatment

**leaching** the process by which soluble constituents are dissolved and filtered through the soil by a percolating fluid

**Legionella** a genus of bacteria, some species of which have caused a type of pneumonia called Legionnaires' disease

**level of concern (LOC)** the concentration in air of an extremely hazardous substance above which there may be serious immediate health effects to anyone exposed to it for short periods

**life cycle of a product** all stages of a product's development, from extraction of fuel for power to production, marketing, use, and disposal

**lifetime average daily dose** value that estimates excess lifetime cancer risk

**lifetime exposure** total amount of exposure to a substance that a human would receive in a lifetime (usually assumed to be 70 years)

**lift** in a sanitary landfill, a compacted layer of solid waste and the top layer of cover material

**light nonaqueous phase liquid (LNAPL)** a nonaqueous phase liquid with a specific gravity less than 1.0. The specific gravity of water is 1.0 so LNAPL floats on top of the water table. Most common petroleum hydrocarbon fuels and lubricating oils are LNAPLs

**limestone scrubbing** use of a limestone and water solution to remove gaseous stack-pipe sulfur before it reaches the atmosphere

**limited degradation** an environmental policy permitting some degradation of natural systems but terminating at a level well below an established health standard

**limiting factor** a condition whose absence or excessive concentration is incompatible with the needs or tolerance of a species or population, and that may have a negative influence on their ability to thrive

**limiting reactant** a reactant that is completely consumed in a chemical reaction

**limit of detection (LOD)** the minimal concentration of a substance being analyzed that has a 99 percent probability of being identified

**liner** a relatively impermeable barrier designed to keep leachate inside a landfill. Liner materials

include plastic and dense clay. Also, an insert or sleeve for sewer pipes to prevent leakage or infiltration

**lipid solubility** the maximal concentration of a chemical that will dissolve in fatty substances. Lipid-soluble substances are insoluble in water. They selectively disperse through the environment via uptake in living tissue

**liquid injection incinerator** commonly used system that relies on high pressure to prepare liquid wastes for incineration by breaking them up into tiny droplets to allow easier combustion

**listed waste** wastes listed as hazardous under RCRA but not subjected to the Toxic Characteristics Listing Process because the dangers they present are considered self-evident

**lithification** the process of converting loose sediment to solid rock

**litter** the highly visible portion of solid waste carelessly discarded outside the regular garbage and trash collection and disposal system. Also, leaves and twigs fallen from forest trees

**littoral zone** that portion of a body of freshwater extending from the shoreline lakeward to the limit of occupancy of rooted plants. Also, a strip of land along the shoreline between the high and low water levels

**Local Emergency Planning Committee (LEPC)** a committee appointed by the state emergency response commission, as required by SARA Title III, to formulate a comprehensive emergency plan for its jurisdiction

**low-density polyethylene (LDPE)** plastic material used for both rigid containers and plastic film

**lower detection limit** the smallest presence of a contaminant that an analytical instrument can reliably detect

**lower explosive limit (LEL)** the concentration of a compound in air below which the mixture will not catch on fire

**lowest acceptable daily dose** the largest quantity of a chemical that will not cause a toxic effect, as determined by animal studies

**lowest achievable emission rate** under the Clean Air Act, the most stringent limits on rate of emissions in a state implementation plan for any source unless the owner demonstrates such limitations are not achievable, or the most stringent emissions limitation achieved in practice, whichever is more stringent

**lowest observed adverse effect level (LOAEL)** the lowest level of a stressor that causes significant differences in test samples

**low-input agriculture** farming that uses lower amounts of pesticides, fertilizers, growth hormones, water, and fossil fuel than are used in current practices

**low-level radioactive waste (LLRW)** wastes less hazardous than most of those associated with a nuclear reactor; generated by hospitals, research laboratories, and certain industries. The Department of Energy, Nuclear Regulatory Commission, and EPA share responsibilities for managing them

**low NOx burners** one of several combustion technologies used to reduce emissions of nitrogen oxides (NOx)

**macropores** secondary soil features such as root holes or desiccation cracks that can create significant conduits for movement of NAPL and dissolved or vapor-phase contaminants. See NONAQUEOUS PHASE LIQUID

**magnetic separation** use of magnets to separate ferrous materials from mixed municipal waste

**magnitude** a measure of the energy released by an earthquake

**major modification** changes to major stationary sources of emissions with respect to Prevention of Significant Deterioration and New Source Review under the Clean Air Act

**majors** larger publicly owned treatment works (POTWs) with flows equal to at least 1 million gallons (3.8 million L) per day (md) or serving a population equivalent to 10,000 persons; certain other POTWs having significant water quality impacts

**major stationary sources** under the Clean Air Act, term used to determine the applicability of Prevention of Significant Deterioration (PSD) and new source regulations. In a nonattainment area, any stationary pollutant source with potential to emit more than 100 tons (91 metric tons) per year is considered a major stationary source. In PSD areas, the cutoff level may be either 100 or 250 tons (91 or 227 metric tons), depending upon the source

**management plan** under the Asbestos Hazard Emergency Response Act (AHERA), a document that each local education agency is required to prepare, describing all activities planned and undertaken by a school to comply with AHERA regulations, including building inspections to identify asbestos-containing materials, response actions, and operations and maintenance programs to minimize the risk of exposure

**manifest** a one-page form used by haulers transporting waste that lists the EPA identification numbers, the type and quantity of waste, the generator when it originated, the transporter

that shipped it, and the storage or disposal facility to which it is being shipped. It includes copies for all participants in the shipping process

**manifest system** tracking of hazardous waste from generation through disposal ("cradle-to-grave") with accompanying manifest documents

**margin of exposure (MOE)** the ratio of the no-observed-adverse-effect-level to the estimated exposure dose

**margin of safety** maximum amount of exposure producing no measurable effect in animals (or studied humans) divided by the actual amount of human exposure in a population

**marine protected area** a region of the ocean set aside to protect marine life from fishing pressure

**marine reserve** an area of the ocean where no fishing is allowed

**marine sanitation device** any equipment or process installed on a vessel to receive, retain, treat, or discharge sewage

**marsh** a type of wetland that does not accumulate appreciable peat deposits and is dominated by vegetation. Marshes may be freshwater or salt water, tidal or nontidal

**material safety data sheet (MSDS)** a compilation of information required under the OSHA Communication Standard on the identity of hazardous chemicals, health and physical hazards, exposure limits, and precautions. Section 311 of SARA requires facilities to submit MSDSs under certain circumstances

**materials recovery facility (MRF)** a facility that processes residually collected mixed recyclables into new products available for market

**maximally (or most) exposed individual** the person with the highest exposure in a given population

**Maximum Acceptable Toxic Concentration** for a given ecological effects test, the range (or geometric mean) between the No Observable Adverse Effect Level and the Lowest Observable Adverse Effects Level

**Maximum Available Control Technology (MACT)** the emission standard for sources of air pollution requiring the maximal reduction of hazardous emissions, taking cost and feasibility into account. Under the Clean Air Act Amendments of 1990, the MACT must not be less than the average emission level achieved by controls on the best performing 12 percent of existing sources, by category of industrial and utility sources

**maximum contaminant level (MCL)** the maximal permissible level of a contaminant in water delivered to any user of a public system. MCLs are enforceable standards

**maximum contaminant level goal (MCLG)** under the Safe Drinking Water Act, a nonenforceable concentration of a drinking water contaminant, set at the level at which no known or anticipated adverse effects on human health occur and that allows an adequate safety margin. The MCLG is usually the starting point for determining the regulated Maximum Contaminant Level (MCL)

**maximum exposure range** estimate of exposure or dose level received by an individual in a defined population that is greater than the 98th percentile dose for all individuals in that population, but less than the exposure level received by the person receiving the highest exposure level

**maximum residue level** the enforceable limit on food pesticide levels in some countries. Levels are set by the Codex Alimentarius Commission, a United Nations agency managed and funded jointly by the World Health Organization and the Food and Agriculture Organization

**maximum sustainable yield** the most a renewal resource can be exploited while still leaving it available for future generations

**maximum tolerated dose** the maximum dose that an animal species can tolerate for a major portion of its lifetime without significant impairment or toxic effect other than carcinogenicity

**measure of effect/measurement end point** a measurable characteristic of an ecological entity that can be related to an assessment end point (e.g., a laboratory test for eight species meeting certain requirements may serve as a measure of effect for an assessment end point, such as survival of fish, aquatic, invertebrate, or algal species under acute exposure)

**measure of exposure** a measurable characteristic of a stressor (such as the specific amount of mercury in a body of water) used to help quantify the exposure of an ecological entity or individual organism

**mechanical aeration** use of a mechanical device to inject air into water to cause a waste stream to absorb oxygen

**mechanical separation** using mechanical means to separate waste into various components

**mechanical turbulence** random irregularities of fluid motion in air caused by buildings or other nonthermal processes

**media** air, water, sediment, rock, or soil, the subject of regulatory concern and activities

**medical surveillance** a periodic comprehensive review of a worker's health status; acceptable elements of such surveillance program are listed in the Occupational Safety and Health Administration standards for asbestos

**medical waste** any solid waste generated in the diagnosis, treatment, or immunization of human beings or animals, in medical research, or in the production or testing of biological materials

**medium-size water system** a water system that serves 3,300–50,000 customers

**mesotrophic** reservoirs and lakes that contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life

**metabolites** any substances produced by biological processes, such as those from pesticides

**metalimnion** the middle layer of a thermally stratified lake or reservoir. In this layer, there is a rapid decrease in temperature with depth. Also called thermocline

**methane** a colorless, nonpoisonous, flammable gas created by anaerobic decomposition of organic compounds. A major component of natural gas used in the home

**methanol** an alcohol that can be used as an alternative fuel or as a gasoline additive. It is less volatile than gasoline; blended with gasoline, it lowers the carbon monoxide emissions but increases hydrocarbon emissions. Used as pure fuel, it produces emissions that are less ozone-forming than those from gasoline. Poisonous to humans and animals if ingested

**methyl orange alkalinity** a measure of the total alkalinity in a water sample in which the color of methyl orange reflects the change in level

**microbial growth** the amplification or multiplication of microorganisms such as bacteria, algae, diatoms, plankton, and fungi

**microbial pesticide** a microorganism that is used to kill a pest but has minimal toxicity to humans

**microclimate** localized climate conditions within an urban area or neighborhood. Also, the climate around a tree or shrub or a stand of trees

**microenvironmental method** a method for sequentially assessing exposure for a series of microenvironments that can be approximated by constant concentrations of a stressor

**microenvironments** well-defined surroundings such as the home, office, or kitchen that can be treated as uniform in terms of stressor concentration

**mineral reserve** the proven amount of ore in the ground that can be recovered under current economic conditions

**minimization** a comprehensive program to minimize or eliminate wastes, usually applied to wastes at their point of origin

**mining of an aquifer (water mining)** withdrawal over a period of groundwater that exceeds the rate of recharge of the aquifer

- mining waste** residues resulting from the extraction of raw materials from the earth
- minors** publicly owned treatment works with flows less than 1 million gallons (3.8 million L) per day
- minor source** new emissions sources or modifications to existing emissions sources that do not exceed NAAQS emission levels
- miscellaneous ACM** interior asbestos-containing building material or structural components, members, or fixtures, such as floor and ceiling tiles; does not include surfacing materials or thermal system insulation
- miscible liquids** two or more liquids that can be mixed and remain mixed under normal conditions
- missed detection** the situation that occurs when a test indicates that a storage tank is not leaking when it is
- mist** liquid particles measuring 40–500 micrometers ( $\mu\text{m}$ ), formed by condensation of vapor. By comparison, fog particles are smaller than 40  $\mu\text{m}$
- mitigation** measures taken to reduce adverse impacts on the environment
- mixed funding** settlements in which potentially responsible parties (PRPs) and the EPA share the cost of a remedial action
- mixed metals** recovered metals not sorted into categories such as aluminum, tin, or steel cans or ferrous or nonferrous metals
- mixed municipal waste** solid waste that has not been sorted into specific categories (such as plastic, glass, yard trimmings, etc.)
- mobile incinerator systems** hazardous waste incinerators that can be transported from one site to another
- mobile source** any nonstationary source of air pollution such as cars, trucks, motorcycles, buses, airplanes, and locomotives
- modified bin method** a method to calculate the required heating or cooling for a building based on how much energy the system would use if outdoor temperatures were within a certain interval and then multiplying the energy use by the time that the temperature interval typically occurs
- modified source** the enlargement of a major stationary pollutant source is often referred to as modification, implying that more emissions will occur
- moisture content** the amount of water lost from soil upon drying to a constant weight, expressed as the weight per unit of dry soil or as the volume of water per unit bulk volume of soil. For a fully saturated medium, moisture content indicates the porosity. Also, the water equivalent of snow on the ground; an indicator of snowmelt flood potential
- molten salt reactor** a thermal treatment unit that rapidly heats waste in a heat-conducting fluid bath of carbonate salt
- monitoring** periodic or continuous surveillance or testing to determine the level of compliance in various media or in humans, plants, and animals
- monitoring well** a well used to obtain water quality samples or measure groundwater levels. Also, a well drilled at a hazardous waste management facility or Superfund site to collect groundwater samples for the purpose of physical, chemical, or biological analysis to determine the amounts, types, and distribution of contaminants in the groundwater beneath the site
- monoclonal antibodies (also called MABs and MCAs)** clones of a molecule, produced in quantity for medical or research purposes. Also, molecules of living organisms that selectively attach to other molecules to which their structure conforms exactly. This also could apply to equivalent activity by chemical molecules
- monomictic** lakes and reservoirs that are relatively deep, do not freeze over during winter, and undergo a single stratification and mixing cycle during the year (usually in the fall)
- Montreal Protocol** a 1987 international treaty that governs stratospheric ozone protection, research, and production and use of ozone-depleting substances. It provides for the end of production of ozone-depleting substances such as CFCs. Under the protocol, a fund was established to assist developing nations in the transition to ozone-safe technologies
- monsoon** a continental weather system caused by uneven heating of land and sea in which winds blow landward and carry rain. In the winter, when the land is warmer than the ocean, the direction of the monsoon reverses, and the wind blows seaward
- moratorium** during the negotiation process, a period of 60–90 days during which the EPA and potentially responsible parties (PRPs) may reach a settlement but no site activities can be conducted
- morbidity** rate of disease incidence
- mortality** death rate
- most probable number** an estimate of microbial density per unit volume of water sample, based on probability theory
- muck soils** wet soil made from decaying plant materials
- mulch** a layer of material (wood chips, straw, leaves, etc.) placed around plants to hold moisture, prevent weed growth, and enrich or sterilize the soil



**multimedia approach** joint approach to the management of environmental media, such as air, water, and land

**multiple chemical sensitivity** a diagnostic label for people who suffer multisystem illnesses as a result of contact with, or proximity to, a variety of airborne agents and other substances

**municipal discharge** discharge of wastewater from treatment plants that process it from households, commercial establishments, and industries in the coastal drainage basin. Combined sewer/separate storm overflows are included in this category

**municipal sewage** wastes (mostly liquid) originating from a community; may be composed of domestic wastewaters and/or industrial discharges

**municipal sludge** semiliquid residue remaining from the treatment of municipal water and wastewater

**municipal solid waste** common garbage or trash generated by industries, businesses, institutions, and homes

**mutagen/mutagenicity** an agent that causes a permanent genetic change in a cell. Mutagenicity is the capacity of a chemical or physical agent to cause such permanent changes

**National Ambient Air Quality Standards (NAAQS)** standards established by the EPA that apply to outdoor air throughout the country

**National Emissions Standards for Hazardous Air Pollutants (NESHAPS)** emissions standards set by the EPA for an air pollutant not covered by NAAQS that may cause an increase in fatalities or serious, irreversible, or incapacitating illness. Primary standards are designed to protect human health, secondary standards to protect public welfare (e.g., building facades, visibility, crops, and domestic animals)

**National Oil and Hazardous Substances Contingency Plan (NOHSCP/NCP)** the federal regulation that guides determination of the sites to be corrected under both the Superfund program and the program to prevent or control spills into surface waters or elsewhere

**National Pollutant Discharge Elimination System (NPDES)** a provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by the EPA, a state, or, where delegated, a tribal government on an Indian reservation

**National Priorities List (NPL)** the EPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial action under Superfund. The list is based primarily on the score a site receives

from the Hazard Ranking System. The EPA is required to update the NPL at least once a year. A site must be on the NPL to receive money from the trust fund for remedial action

**National Response Center** the federal operations center that receives notifications of all releases of oil and hazardous substances into the environment; open 24 hours a day, operated by the U.S. Coast Guard, which evaluates all reports and notifies the appropriate agency

**National Response Team (NRT)** representatives of 13 federal agencies that, as a team, coordinate federal responses to nationally significant incidents of pollution (an oil spill, a major chemical release, or a Superfund response action) and provide advice and technical assistance to the responding agency(ies) before and during a response

**natural gas** a fossil fuel composed primarily of methane created as a by-product when bacteria decompose organic material under anaerobic conditions

**navigable waters** streams and rivers sufficiently deep and wide for navigation by all or specified vessels; such waters in the United States are under federal jurisdiction and are protected by certain provisions of the Clean Water Act

**necrosis** death of plant or animal cells or tissues. In plants, necrosis can discolor stems or leaves or kill the plant

**nematicide** a chemical agent that is destructive to nematodes

**nephelometric** method of measuring turbidity in a water sample by passing light through the sample and measuring the amount of the light that is deflected

**netting** a concept in which all emissions sources in the same area owned or controlled by a single company are treated as one large source, thereby allowing flexibility in controlling individual sources in order to meet a single emissions standard

**neutralization** decreasing the acidity or alkalinity of a substance by adding alkaline or acidic materials, respectively

**new source** any stationary source of air pollution built or modified after publication of final or proposed regulations

**New Source Performance Standards (NSPS)** uniform national EPA air emission and wastewater standards that limit the amount of pollution from new sources or from modified existing sources

**New Source Review (NSR)** a Clean Air Act requirement that state implementation plans

must include a permit review of the construction and operation of new and modified stationary pollution sources in nonattainment areas

**niche** the functional role of a species in an ecosystem

**nitrate** a compound containing nitrogen that can exist in the atmosphere or as a dissolved gas in water. Nitrates in water can cause severe illness in infants and domestic animals. A plant nutrient and inorganic fertilizer, nitrate is found in septic systems, animal feedlots, agricultural fertilizers, manure, industrial wastewaters, sanitary landfills, and garbage dumps

**nitrification** the process whereby ammonia in wastewater is oxidized to nitrite and then to nitrate by bacterial or chemical reactions

**nitritotriacetic acid (NTA)** a compound that replaces phosphates in detergents

**nitrite** an intermediate in the process of nitrification. Also, nitrous oxide salts used in food preservation

**nitrogen cycle** a major nutrient cycle that converts atmospheric nitrogen to bioavailable forms, eventually returning it to the atmosphere

**nitrogenous wastes** animal or vegetable residues that contain significant amounts of nitrogen

**nitrophenols** synthetic organopesticides containing carbon, hydrogen, nitrogen, and oxygen

**“no further remedial action planned”** determination made by the EPA after a preliminary assessment that a site does not pose a significant risk and so requires no further activity under CERCLA

**nonbiodegradable** a pollutant that is not destroyed in a reasonable amount of time by organisms that occur naturally in the soil or water

**nonrenewable resource** a resource that is in limited supply and formed much more slowly than it is used

**no observable adverse effect level (NOAEL)** an exposure level at which there is no statistically or biologically significant increase in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered as adverse or as precursors to adverse effects

**no-observed-effect-level (NOEL)** exposure level at which there are no statistically or biologically significant differences in the frequency or severity of any effect in the exposed or control populations

**nonaqueous phase liquid (NAPL)** contaminant that remains undiluted as the original bulk liquid in the subsurface (e.g. spilled oil)

**nonattainment area** an area that does not meet one or more of the National Ambient Air Quality Standards for the criteria pollutants designated in the Clean Air Act

**Non-Binding Allocations of Responsibility (NBAR)** a process for the EPA to propose a method for potentially responsible parties (PRPs) to allocate costs among themselves

**noncommunity water system** a public water system that is not a community water system (e.g., the water supply at a campsite or national park)

**noncompliance coal** any coal that emits more than three pounds (1.4 kg) of sulfur dioxide per million BTU when burned. Also known as high-sulfur coal

**noncontact cooling water** water used for cooling that does not have direct contact with any raw material, product, by-product, or waste

**nonconventional pollutant** any pollutant not statutorily listed or that is poorly understood by the scientific community

**nondegradation** an environmental policy that disallows any lowering of naturally occurring quality regardless of preestablished health standards

**nondischarging treatment plant** a treatment plant that does not discharge treated wastewater into any stream or river. Most are pond systems that dispose of the total flow they receive by means of evaporation or percolation to groundwater, or facilities that dispose of their waste water by recycling or reuse (e.g., spray irrigation or groundwater discharge)

**nonferrous metals** metals such as aluminum, lead, and copper that contain no iron. Products made all or in part from such metals include containers, packaging, appliances, furniture, electronic equipment, and aluminum foil

**nonfriable asbestos-containing material** any material containing more than 1 percent asbestos that cannot be crumbled, pulverized, or reduced to powder by hand pressure

**nonhazardous industrial waste** industrial waste in wastewater not considered municipal solid waste or hazardous waste under RARA

**nonionizing electromagnetic radiation** radiation that does not change the structure of atoms but does heat tissue and may cause harmful biological effects. Includes microwaves, radio waves, and low-frequency electromagnetic fields from high-voltage transmission lines

**nonmethane hydrocarbon (NMHC)** the sum of all hydrocarbon air pollutants except methane; significant precursors to ozone formation

- nonmethane organic gases (NMOG)** the sum of all organic air pollutants. Excluding methane, they account for aldehydes, ketones, alcohols, and other pollutants that are not hydrocarbons but are precursors of ozone
- nonpoint sources** diffuse pollution sources (i.e., without a single point of origin or not introduced into a receiving stream from a specific outlet). The pollutants generally are carried off the land by storm water
- nonpotable water** water that is unsafe or unpalatable to drink because it contains pollutants, contaminants, minerals, or infective agents
- nonroad emissions** pollutants emitted by combustion engines on farm and construction equipment, gasoline-powered lawn and garden equipment, and power boats and outboard motors
- nontransient noncommunity water system** a public water system that regularly serves at least 25 of the same nonresident persons per day for more than six months per year
- notice of deficiency** an EPA request to a facility owner or operator requesting additional information before a preliminary decision on a permit application can be made
- notice of intent to cancel** notification sent to registrants when the EPA decides to cancel registration of a product containing a pesticide
- notice of intent to deny** notification by the EPA of its preliminary intent to deny a permit application
- notice of intent to suspend** notification sent to a pesticide registrant when the EPA decides to suspend product sale and distribution because of failure to submit requested data in a timely and/or acceptable manner, or because of imminent hazard
- nuclear reactors and support facilities** uranium mills, commercial power reactors, fuel reprocessing plants, and uranium enrichment facilities
- nuclear winter** prediction by some scientists that smoke and debris rising from massive fires of a nuclear war could block sunlight for weeks or months, cooling the Earth's surface and producing climate changes that could, for example, negatively affect world agricultural and weather patterns
- nutrient** any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in wastewater but also is associated with other essential and trace elements
- nutrient pollution** contamination of water resources by excessive inputs of nutrients. In surface waters, excess algal production is a major concern
- ocean discharge waiver** a variance from Clean Water Act requirements for discharges into marine waters
- odor threshold** the minimal odor of a water or air sample that can be detected after successive dilutions with odorless water
- offsets** a concept whereby emissions from new or modified stationary sources are balanced by reductions from existing sources to stabilize total emissions
- off-site facility** a hazardous waste treatment, storage, or disposal area that is located away from the generating site
- offstream use** water withdrawn from surface water or groundwater sources for use at another place
- oil** a naturally occurring liquid composed of a complex mixture of hydrocarbons
- oil and gas waste** gas and oil drilling mud, oil production brines, and other waste associated with exploration for, development of, and production of crude oil or natural gas
- oil desulfurization** widely used precombustion method for reducing sulfur dioxide emissions from oil-burning power plants. The oil is treated with hydrogen, which removes some of the sulfur by forming hydrogen sulfide gas
- oil fingerprinting** a method that identifies sources and types of petroleum products and allows spills to be traced to their source
- oil shale** a kerogen-bearing sedimentary rock that yields liquid or gaseous hydrocarbons when heated
- oil trap** any geologic feature that accumulates oil or gas by preventing its upward movement
- oligotrophic lakes** deep, clear lakes with few nutrients, little organic matter, and a high dissolved-oxygen level
- on-scene coordinator (OSC)** the predesignated EPA, U.S. Coast Guard, or Department of Defense official who coordinates and directs Superfund removal actions or Clean Water Act oil or hazardous spill responses
- on-site facility** a hazardous waste treatment, storage, or disposal area that is located on the generating site
- open burning** uncontrolled fires in an open dump
- open dump** an uncovered site used for disposal of waste without environmental controls
- operable unit** term for each of a number of separate activities undertaken as part of a Superfund site cleanup. A typical operable unit would be removal of drums and tanks from the surface of a site

**operating conditions** conditions specified in a RCRA permit that dictate how an incinerator must operate as it burns different waste types. A trial burn is used to identify operating conditions needed to meet specified performance standards

**operation and maintenance** activities conducted after a Superfund site action is completed to ensure that the cleanup action is effective. Also, actions taken after construction to ensure that facilities to treat wastewater will be properly operated and maintained to achieve efficiency levels and wastewater limitations in an optimal manner. It can also be applied to an ongoing asbestos management plan in a school or other public building, including regular inspections, various methods of maintaining asbestos in place, and removal when necessary

**optimal corrosion control treatment** an erosion control treatment that minimizes the lead and copper concentrations at user's taps while also ensuring that the treatment does not violate any national primary drinking water regulations

**oral toxicity** ability of a pesticide or other chemical to cause injury when ingested

**ore** a natural material that is sufficiently enriched in one or more minerals to be mined profitably

**organic** referring to or derived from living organisms. In chemistry, any compound containing carbon and hydrogen

**organic matter** carbonaceous waste contained in plant or animal matter and originating from domestic or industrial sources

**organism** any form of animal or plant life

**organophosphates** pesticides that contain phosphorus

**organophyllic** a substance that readily combines with organic compounds

**organotins** chemical compounds used in antifouling paints to protect the hulls of boats and ships, buoys, and pilings from marine organisms such as barnacles

**original generation point** location where regulated medical or other material first becomes waste

**osmosis** the passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane that allows passage of the solvent (water) but not the dissolved solids

**other ferrous metals** recyclable metals from strapping, furniture, and metal found in tires and consumer electronics but not metals found in construction materials or cars, locomotives, and ships

**other glass** recyclable glass from furniture, appliances, and consumer electronics. Does not

include glass from transportation products (cars, trucks, or shipping containers) and construction or demolition debris

**other nonferrous metals** recyclable nonferrous metals such as lead, copper, and zinc from appliances, consumer electronics, and nonpackaging aluminum products. Does not include nonferrous metals from industrial applications and construction and demolition debris

**other paper** for recyclable paper from books; third-class mail; commercial printing; paper towels, plates, and cups; and other nonpackaging paper such as posters, photographic papers, cards and games, milk cartons, folding boxes, bags, wrapping paper, and paperboard. Does not include wrapping paper or shipping cartons

**other plastics** recyclable plastic from appliances, eating utensils, plates, containers, toys, and various kinds of equipment. Does not include heavy-duty plastics such as yielding materials

**other solid waste** recyclable nonhazardous solid wastes, other than municipal solid waste, covered under Subtitle D of RARA

**other wood** recyclable wood from furniture, consumer electronics, cabinets, and other nonpackaging wood products. Does not include lumber and tree stumps recovered from construction and demolition activities and industrial process waste such as shavings and sawdust

**outdoor air supply** air drawn into a building from outside

**outfall** the place where effluent is discharged into receiving waters

**overdraft** the pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin; results in a depletion, or "mining," of the groundwater in the basin

**overfire air** air forced into the top of an incinerator or boiler to fan the flames

**overflow rate** one of the guidelines for design of the settling tanks and clarifiers in a treatment plant; used by plant operators to determine whether tanks and clarifiers are over- or underused

**overgrazing** the consumption by too many animals of plant cover, impeding regrowth and slowing the replacement of sustainable biomass

**overland flow** a land application technique that cleanses wastewater by allowing it to flow over a sloped surface. As the water flows over the surface, contaminants are absorbed and the water is collected at the bottom of the slope for reuse

**overturn** one complete cycle of top-to-bottom mixing of previously stratified water masses. This phenomenon may occur in spring or fall or after



storms and results in uniformity of chemical and physical properties of water at all depths

**oxidation** the chemical addition of oxygen to break down pollutants or organic waste (e.g., destruction of chemicals such as cyanides, phenols, and organic sulfur compounds in sewage by bacterial and chemical means). The loss of electrons by an element, compound, or ion

**oxidation pond** an artificial (anthropogenic) body of water in which waste is consumed by bacteria, used most frequently with other waste-treatment processes

**oxidation-reduction potential** the electric potential required to transfer electrons from one compound or element (the oxidant) to another compound (the reducer)

**oxygenated fuels** gasoline that has been blended with alcohols or ethers that contain oxygen in order to reduce carbon monoxide and other emissions

**oxygenated solvent** an organic solvent containing oxygen as part of the molecular structure. Alcohols and ketones are oxygenated compounds often used as paint solvents

**ozonation/ozonator** application of ozone to water for disinfection or for taste and odor control. The ozonator is the device that does this

**ozone depletion** destruction of the stratospheric ozone layer that shields the earth from ultraviolet radiation harmful to life. This destruction of ozone is caused by the breakdown of certain chlorine- and/or bromine-containing compounds (chlorofluorocarbons or halons), which break down when they reach the stratosphere and then catalytically destroy ozone molecules

**ozone hole** a thinning break in the stratospheric ozone layer. Designation of the amount of such depletion as an "ozone hole" is made when the detected amount of depletion exceeds 50 percent. Seasonal ozone holes have been observed over both the Antarctic and Arctic regions, part of Canada, and the extreme northeastern United States

**ozone layer** the protective layer in the atmosphere, about 15 miles (24 km) above the ground, that absorbs some of the Sun's ultraviolet rays, thereby reducing the amount of potentially harmful radiation that reaches the Earth's surface

**packed bed scrubber** an air pollution control device in which emissions pass through alkaline water to neutralize hydrogen chloride gas

**packed tower** a pollution control device that forces dirty air through a tower packed with crushed rock or wood chips while liquid is sprayed over the packing material. The pollut-

ants in the airstream either dissolve or chemically react with the liquid

**packer** an inflatable gland, or balloon, used to create a temporary seal in a borehole, probe hole, well, or drive casing. It is made of rubber or nonreactive materials

**paper processor/plastics processor** factory or plant where recovered paper or plastic products and materials are sorted, decontaminated, and prepared for final recycling

**paraquat** a standard herbicide used to kill various types of crops, including marijuana. Causes lung damage if smoke from the crop is inhaled

**parasite** an organism that depends upon another for nourishment or some other benefit while causing harm to it

**Parshall flume** device used to measure the flow of water in an open channel

**particle count** results of a microscopic examination of treated water with a special particle counter that classifies suspended particles by number and size

**particulate loading** the mass of particulates per unit volume of air or water

**partition coefficient** measure of the sorption phenomenon, whereby a pesticide is divided between the soil and water phases; also referred to as adsorption partition coefficient

**passive smoking/secondhand smoke** inhalation of tobacco smoke produced by others

**passive treatment walls** technology in which a chemical reaction takes place when contaminated groundwater has contact with a barrier such as limestone or a wall containing iron filings

**pathogens** microorganisms (e.g., bacteria, viruses, or parasites) that can cause disease in humans, animals, and plants

**pathway** the physical course a chemical or pollutant takes from its source to the exposed organism

**peak electricity demand** the maximal electricity used to meet the cooling load of a building or buildings in a given area

**peak levels** levels of airborne pollutant contaminants much higher than average or occurring for short periods in response to sudden releases

**percent saturation** the amount of a substance that is dissolved in a solution compared to the amount that could be dissolved in it

**perched water** zone of unpressurized water held above the water table by impermeable rock or sediment

**percolating water** water that passes through rocks or soil under the force of gravity

**percolation** the movement of water downward through subsurface soil layers until the water table is reached. Under certain conditions also can involve the upward movement of water. This term is sometimes applied to the slow seepage of water through a filter

**performance bond** cash or securities deposited before a landfill operating permit is issued, which are held to ensure that all requirements for operating and subsequently closing the landfill are performed. The money is returned to the owner (bond is released) after proper closure of the landfill is finished. If contamination or other problems appear at any time during operation or upon closure and are not addressed, the owner must forfeit all or part of the bond, which is then used to pay for cleanup costs

**performance data (for incinerators)** information collected during a trial burn on concentrations of designated organic compounds and pollutants found in incinerator emissions. Data analysis must show that the incinerator meets performance standards under operating conditions specified in its permit

**performance standards** regulatory requirements limiting the concentrations of designated organic compounds, particulate matter, and hydrogen chloride in emissions from incinerators. Also, operating standards established by the EPA for various permitted pollution control systems, asbestos inspections, and various program operations and maintenance requirements

**periphyton** microscopic underwater plants and animals that are firmly attached to solid surfaces such as rocks, logs, and pilings

**permeability** the rate at which liquids pass through soil or other materials

**permissible dose** the dose of a chemical that may be received by an individual without the expectation of a significantly harmful result

**permissible exposure limit (PEL)** federal limit for workplace exposure to contaminants as established by OSHA

**permit** an authorization, license, or equivalent control document issued by the EPA or an approved state agency to implement the requirements of an environmental regulation (e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions)

**persistence** the length of time a compound stays in the environment

**persistent bioaccumulative toxic chemical** a nonbiodegradable toxin that is released into and accumulates in the environment

**persistent pesticides** pesticides that do not break down chemically or only break down very slowly and remain in the environment after a growing season

**personal air samples** air samples taken with a pump that is directly attached to a worker with the collecting filter and cassette placed in the worker's breathing zone; required under OSHA asbestos standards and the EPA worker protection rule

**personal measurement** a measurement collected from an individual's immediate environment

**personal protective equipment** clothing and equipment worn by pesticide mixers, loaders and applicators and reentry workers, hazmat emergency responders, workers cleaning up Superfund sites, and others to reduce their exposure to potentially hazardous chemicals and other pollutants

**pest** an insect, rodent, nematode, fungus, weed, or other form of terrestrial or aquatic plant or animal life that is injurious to health or the environment

**pest control operator** person or company that applies pesticides as a business (e.g., exterminator); usually describes household services, not agricultural applications

**pesticide** substance or mixture of pesticides intended for preventing, destroying, repelling, or mitigating any pest. Also, any substance or mixture developed for use as a plant regulator, defoliant, or desiccant

**Pesticide Regulation Notice** formal notice to pesticide registrants about important changes in regulatory policy, procedures, and regulations

**pesticide tolerance** the amount of pesticide residue allowed by law to remain in or on a harvested crop. The EPA sets these levels below the amount where the compounds might be harmful to consumers

**petroleum** crude oil or its components that are liquid under normal conditions of temperature and pressure. The term includes petroleum-based substances comprising a complex blend of hydrocarbons derived from crude oil through the process of separation, conversion, upgrading, and finishing, such as motor fuel, jet oil, lubricants, petroleum solvents, and used oil

**petroleum derivatives** chemicals formed when gasoline breaks down in contact with groundwater

**pH (power of hydrogen)** a quantity that measures the degree of the basic or acid condition of a liquid. The pH typically ranges from 0 to 14, where 7 is neutral; less than 7 is acidic and greater than 7 is basic. Natural waters typically have a pH between 6.5 and 8.5

**pharmacokinetics** the study of the way that drugs move through the body after they are inhaled, absorbed through the skin, swallowed, or injected

**phenolphthalein alkalinity** the alkalinity in a water sample measured by the amount of standard acid needed to lower the pH to a level of 8.3 as indicated by the change of color of the indicator chemical (phenolphthalein) from pink to clear

**phenols** organic compounds that are by-products of petroleum refining, tanning, and textile, dye, and resin manufacturing. Low concentrations cause taste and odor problems in water; higher concentrations can kill aquatic life and humans

**phosphates** chemical compounds containing phosphorus

**phosphogypsum piles (stacks)** by-products generated during the production of phosphoric acid from phosphate rock

**phosphorus plants** facilities using electric furnaces to produce elemental phosphorus for commercial use, such as high-grade phosphoric acid, phosphate-based detergent, and organic chemicals use

**photochemical oxidants** air pollutants formed by the action of sunlight on oxides of nitrogen and hydrocarbons

**photochemical smog** air pollution caused by chemical reactions of sunlight and various pollutants emitted from different sources

**photosynthesis** the manufacture by plants of carbohydrates and oxygen from carbon dioxide mediated by chlorophyll in the presence of sunlight

**physical and chemical treatment** processes generally used in large-scale wastewater treatment facilities. Physical processes may include air-stripping or filtration. Chemical treatment includes coagulation, chlorination, or ozonation. The term also can refer to treatment of toxic materials in surface water and groundwater, oil spills, and some methods of addressing hazardous materials on or in the ground

**phytoplankton** that portion of the plankton community that comprises tiny autotrophic plants (e.g., algae, diatoms). They form the base of the food chain for aquatic animals

**phytoremediation** the use of plants and trees to remove or neutralize contaminants, as in polluted soil or water. It is a low-cost remediation option for sites with widely dispersed contamination at low concentrations

**phytotreatment** the cultivation of specialized plants that absorb specific contaminants from the soil through their roots or foliage. This pro-

cess reduces the concentration of contaminants in the soil but incorporates them into biomasses that may be released back into the environment when the plant dies or is harvested

**piezometer** a nonpumping well, generally of small diameter, for measuring the elevation (but not sampling) of the water table

**pilot test** preliminary or initial small-scale evaluation of a cleanup technology under actual site conditions to identify potential problems prior to full-scale implementation

**plankton** tiny plants and animals that live in water

**plasma arc reactors** devices that use an electric arc to decompose organic and inorganic materials thermally at ultrahigh temperatures into gases and a vitrified slag residue

**plasmid** a circular piece of DNA that exists apart from the chromosome and replicates independently of it. Bacterial plasmids carry information that renders the bacteria resistant to antibiotics. Plasmids often are used in genetic engineering to insert desired genes into organisms

**plate tower scrubber** an air pollution control device that neutralizes hydrogen chloride gas by bubbling alkaline water through it via holes in a series of metal plates

**plug flow** type of flow that occurs in tanks, basins, or reactors when a concentrated volume (slug) of water moves through without dispersing or mixing with the rest of the water flowing through

**plugging** act or process of stopping the flow of water, oil, or gas into or out of a formation through a borehole or well

**plume** a visible or measurable discharge of a contaminant from a given point of origin. Also, the area of radiation leaking from a damaged reactor. In hydrogeology, the three-dimensional shape a contaminant mass assumes within an aquifer after a release to the groundwater

**plutonium** a radioactive metallic element chemically similar to uranium

**PM10/PM2.5** PM10 is measure of particles in the atmosphere with a diameter of less than or equal to a nominal 10 micrometers. PM2.5 is a measure of particles in the air that are smaller than or equal to 2.5 micrometers. PM10 has been the pollutant particulate level standard against which the EPA has been measuring Clean Air Act compliance. On the basis of newer scientific findings, the agency is considering regulations that will make PM2.5 the new measurement standard

**pneumoconiosis** health conditions characterized by permanent deposition of substantial amounts of particulate matter in the lungs and by the tissue reaction to its presence; can range from

relatively harmless forms of sclerosis to the destructive fibrotic effect of silicosis

**point-of-contact measurement of exposure** estimating exposure by measuring concentrations over time (while the exposure is taking place) at or near the place where it is occurring

**point-of-disinfectant application** the place where disinfectant is applied and water downstream of that point is not subject to recontamination by surface water runoff

**point-of-use treatment device** a treatment device applied to a single tap or outlet to reduce contaminants in the drinking water

**point source** a stationary location or fixed facility from which pollutants are discharged; any single identifiable source of pollution (e.g., a pipe, ditch, ship, ore pit, factory smokestack)

**polar bond** a covalent bond in which the bonding electrons are not equally shared by the two atoms. Polar compounds generally are soluble in water

**pollen** the fertilizing element of flowering plants that also forms a background air pollutant

**pollutant** any substance introduced into the environment that adversely affects the usefulness of a resource or the health of humans, animals, or ecosystems

**pollutant pathways** avenues for distribution of pollutants. In most buildings, for example, HVAC systems are the primary pathways, but all building components can interact to affect air movement

**Pollutant Standard Index (PSI)** indicator of one or more pollutants that may be used to inform the public about the potential for adverse health effects from air pollution in major cities

**pollution** generally, the presence of a substance in the environment that, because of its chemical composition or quantity, prevents the functioning of natural processes and produces undesirable environmental and health effects. Under the Clean Water Act, for example, the term has been defined as the artificial alteration of the physical, biological, chemical, and radiological integrity of water and other media

**pollution prevention** identifying areas, processes, and activities that create excessive waste products or pollutants in order to reduce or prevent them by altering or eliminating a process

**polonium** a radioactive element that occurs in pitchblende and other uranium-containing ores

**polyelectrolytes** synthetic chemicals that help solids to clump during sewage treatment

**polyethylene terephthalate (PETE)** thermoplastic material used in plastic soft drink and rigid containers

**polymer** a natural or synthetic chemical structure where two or more similar molecules are joined to form a more complex molecular structure (e.g., polyethylene in plastic)

**population** a group of interbreeding organisms occupying a particular space. Also, the number of humans or other living creatures in a designated area

**population at risk** a population subgroup that is more likely to be exposed to a chemical or is more sensitive to the chemical than is the general population

**porosity** the amount of open or pore space in soil, gravel, sediment, or rock. Percentage of open spaces within a solid

**portal-of-entry effect** a local effect produced in the tissue or organ of first contact between a toxicant and the biological system

**postchlorination** addition of chlorine to wastewater for disinfectant purposes after it has been treated

**postclosure** the period after the shutdown of a waste management or manufacturing facility; for monitoring purposes, often considered to be 30 years

**postconsumer materials/waste** materials or finished products that have served their intended use and have been diverted or recovered from waste destined for disposal. Postconsumer materials are part of the broader category of recovered materials

**postconsumer recycling** use of materials generated from residential and consumer waste for new or similar purposes (e.g., converting wastepaper from offices into corrugated boxes or newsprint)

**potable water** water that is safe for drinking, bathing, and cooking

**potential dose** the amount of a compound contained in material swallowed, breathed, or applied to the skin

**potentially responsible party (PRP)** any individual or company, including owners, operators, transporters, or generators, that may be responsible for or contributed to a spill or other contamination at a Superfund site. Whenever possible, through administrative and legal actions, the EPA requires PRPs to clean up hazardous sites they have contaminated

**potentiation** the ability of one chemical to increase the effect of another chemical

**potentiometric surface** the surface to which water in an aquifer will rise under hydrostatic pressure (the water table)

**precautionary principle** when information about potential risks is incomplete, basing decisions



about the best ways to manage or reduce risks on a preference for avoiding unnecessary health risks instead of on unnecessary economic expenditures

**prechlorination** the addition of chlorine at the beginning of the treatment process. Done mainly to disinfect and control tastes, odors, and aquatic growths, and to aid in coagulation and settling

**precipitate** a substance separated from a solution or suspension by chemical or physical change

**precipitation** removal of hazardous solids from liquid waste to permit safe disposal; removal of particles from airborne emissions as in rain (e.g., acid precipitation)

**precipitator** pollution control device that collects particles from an airstream

**precision** agreement among repeated measurements

**preconsumer materials/waste** materials generated in manufacturing and converting processes such as scrap, trimmings, and cuttings. Includes print overruns, overissue publications, and obsolete inventories

**precursor** in photochemistry, a compound antecedent to a pollutant. For example, volatile organic compounds (VOCs) and nitrogen oxides react in sunlight to form ozone or other photochemical oxidants. As such, VOCs and nitrogen oxides are precursors

**preharvest interval** the time between the last pesticide application and harvest of the treated crops

**preliminary assessment** the process of collecting and reviewing available information about a known or suspected waste site or release

**pressed wood products** materials used in building and furniture construction that are made from wood veneers, particles, or fibers bonded together with an adhesive applied under heat and pressure

**pressure sewers** a system of pipes in which water, wastewater, or other liquid is pumped to a higher elevation

**pretreatment** processes used by industries to reduce, eliminate, or alter the nature of wastewater pollutants from nondomestic sources before they are discharged into publicly owned treatment works

**prevalent levels** levels of airborne contaminant occurring under normal conditions

**prevalent level samples** air samples taken under normal conditions (also known as ambient background samples)

**Prevention of Significant Deterioration (PSD)** an EPA program in which state and/or federal permits are required in order to restrict emissions from new or modified sources in places where air

quality already meets or exceeds primary and secondary ambient air quality standards

**primacy** having the primary responsibility for administering and enforcing regulations

**primary effect** an effect in which the stressor acts directly on the ecological component of interest, not on other parts of the ecosystem

**primary standards** national ambient air quality standards designed to protect human health with an adequate margin for safety

**primary treatment** first stage of wastewater treatment in which solids are removed by screening and settling

**primary waste treatment** initial steps in wastewater treatment; screens and sedimentation tanks are used to remove most materials that float or settle. Primary treatment removes about 30 percent of carbonaceous biochemical oxygen demand (BOD) from domestic sewage

**Principal Organic Hazardous Constituents (POHCs)** hazardous compounds monitored during an incinerator's trial burn, selected for high concentration in the waste feed and difficulty of combustion

**prions** microscopic particles made of protein that can cause disease

**prior appropriation** a doctrine of water law that allocates the rights to use water on a first-come, first-served basis

**probability of detection** the likelihood, expressed as a percentage, that a test method will correctly identify a leaking tank

**process variable** a physical or chemical quantity that is monitored and controlled in the operation of a water treatment plant or industrial plant

**process verification** verifying that raw materials, water usage, waste treatment methods, production rate, and other factors of quantity and quality of pollutants contained in discharges are described in the permit application and issued permit

**process wastewater** water that has contact with any raw material, product, by-product, or waste

**process weight** total weight of all materials, including fuel, used in a manufacturing process; used to calculate the allowable particulate emission rate

**producers (primary producers)** plants that perform photosynthesis and provide food to consumers

**product** in chemistry, a substance that is formed in a chemical reaction. In manufacturing, the materials used or the finished goods that are available for sale

**product level** a measure of the amount of a product in a storage tank

**products of incomplete combustion (PICs)**

organic compounds formed by combustion. Usually generated in small amounts and sometimes toxic, PICs are heat-altered versions of the original material fed into the incinerator (e.g., charcoal is a PIC from burning wood)

**product water** water that has passed through a water treatment plant and is ready to be delivered to consumers

**proportionate mortality ratio (PMR)** the number of deaths from a specific cause in a specific period per 100 deaths from all causes during the same period

**proposed plan** a plan for a site cleanup that is available to the public for comment

**proteins** complex nitrogenous organic compounds of high molecular weight made of amino acids; essential for growth and repair of animal tissue

**protocol** a series of formal steps for conducting a test

**protoplast** a membrane-bound cell from which the outer wall has been partially or completely removed. The term often is applied to plant cells

**protozoa** one-celled animals that are larger and more complex than bacteria. May cause disease

**public comment period** the time allowed for the public to express its views and concerns regarding an action by the EPA

**public health approach** regulatory and voluntary focus on effective and feasible risk management actions at the national and community levels to reduce human exposures and risks, with priority given to reducing exposures with the greatest impacts in terms of the number of people affected and severity of the effect

**public health context** the incidence, prevalence, and severity of diseases in communities or populations and the factors that account for them, including infections, exposure to pollutants, and other exposures or activities

**public hearing** a formal meeting wherein EPA officials hear the public's views and concerns about an EPA action or proposal. The EPA is required to consider such comments when evaluating its actions. Public hearings must be held upon request during the public comment period

**publicly owned treatment works (POTWs)** a waste-treatment works owned by a state government, unit of local government, or Indian tribe and usually designed to treat domestic wastewaters

**public notice** notification by the EPA informing the public of actions such as the issuance of a draft permit or scheduling of a hearing. The EPA is required to ensure proper public notice,

including publication in newspapers and broadcast over radio and television stations

**public water system** a system that provides water for human consumption to at least 15 service connections or regularly serves 25 individuals

**pumping station** mechanical device installed in sewer or water system or other liquid-carrying pipelines to pump the liquids to a higher elevation

**pumping test** a test conducted to determine aquifer or well characteristics

**purging** removing stagnant air or water from a sampling zone or equipment prior to sample collection

**putrefaction** biological decomposition of organic matter associated with anaerobic conditions.

**putrescible** able to rot quickly enough to cause odors and attract flies

**pyrolysis** decomposition of a chemical by extreme heat

**qualitative data** information that cannot be easily described with numbers (e.g., feel, taste, image, reputation)

**qualitative use assessment** report summarizing the major uses of a pesticide including percentage of crop treated and amount of pesticide used on a site

**quality assurance/quality control** a system of procedures, checks, audits, and corrective actions to ensure that research, design, performance, environmental monitoring and sampling, and other technical and reporting activities are of the highest achievable quality

**quantitative data** information that can be easily expressed using numbers (e.g., size, mass, temperature)

**quench tank** a water-filled tank used to cool incinerator residues or hot materials during industrial processes

**radiation standards** regulations that set maximal exposure limits for protection of the public from radioactive materials

**radioactive decay** spontaneous change in an atom by emission of charged particles (alpha or beta) and/or gamma rays; also known as radioactive disintegration and radioactivity

**radioisotopes** chemical variants of radioactive elements with potentially oncogenic, teratogenic, and mutagenic effects on the human body

**radionuclide** radioactive particle, anthropogenic or natural, with a definitive atomic weight. Can remain as a soil or water pollutant for long periods, depending upon half-life

**radius of influence** the radial distance from the center of a well or boring to the point where there is no lowering of the water table or potentiometric

surface (the edge of the cone of depression). Also, the radial distance from an extraction well that has adequate airflow for effective removal of contaminants when a vacuum is applied

**radius of vulnerability zone** the maximal distance from the point of release of an airborne hazardous substance in which the airborne concentration may reach the level of concern under specified weather conditions

**rainbow report** comprehensive document giving the status of all pesticides now or ever in registration or special reviews. Known as the "rainbow report because chapters are printed on different colors of paper

**rangeland** land used for grazing livestock

**rasp** a machine that grinds waste into a manageable material and helps prevent odor

**raw sewage** untreated wastewater and its contents

**raw water** intake water prior to any treatment or use

**reactant** a substance that is consumed in a chemical reaction

**reactivity** refers to those hazardous wastes that are normally unstable and readily undergo violent chemical change but do not explode

**reaeration** introduction of air into the lower layers of a reservoir. As the air bubbles form and rise, the oxygen dissolves into the water and increases the dissolved oxygen concentration. The rising bubbles also move deeper water to the surface, where it absorbs oxygen from the atmosphere

**real-time monitoring** monitoring and measuring environmental conditions with technology and communication systems that provide current data

**reasonable maximum exposure** the maximal exposure reasonably expected to occur in a population

**reasonable worst case** an estimate of the individual dose, exposure, or risk level received by an individual in a defined population that is greater than the 90th percentile but less than that received by anyone in the 98th percentile in the same population

**Reasonably Available Control Measure (RACM)** a broadly defined term referring to technological and other measures for pollution control

**Reasonably Available Control Technology (RACT)** control technology that is reasonably available and both technologically and economically feasible. Usually applied to existing sources or air pollution in nonattainment areas

**recarbonization** process in which carbon dioxide is bubbled into water being treated to lower the pH

**receiving waters** a river, lake, ocean, stream, or other watercourse into which wastewater or treated effluent is discharged

**receptor** ecological entity exposed to a stressor

**recharge** the process by which water is added to a zone of saturation, usually by percolation from the soil surface (e.g., the recharge of an aquifer)

**recharge area (or zone)** a land area in which water reaches the zone of saturation from surface infiltration (e.g., where rainwater soaks through the soil and enters an aquifer)

**recharge rate** the quantity of water per unit of time that replenishes or refills an aquifer

**reclamation** restoration of materials found in the waste stream to some beneficial use. In mining, placement of fill (usually tailings and spoils) and reestablishment of vegetation to restore functioning ecology to an area where minerals have been extracted

**recombinant bacteria** a microorganism whose genetic makeup has been altered by deliberate introduction of new genetic elements. The offspring of these altered bacteria also contain these new genetic elements

**recombinant DNA** the new DNA that is formed by combining pieces of DNA from different organisms or cells

**Recommended Maximum Contaminant Level (RMCL)** the maximal level of a contaminant in drinking water at which no known or anticipated adverse effect on human health would occur and that includes an adequate margin of safety

**reconstruction of dose** estimating exposure after it has occurred by using evidence within an organism such as chemical levels in tissue or fluids

**Record of Decision (ROD)** a public document that explains which cleanup alternative(s) will be used at National Priorities List sites where CERCLA trust funds pay for the cleanup

**recovery rate** percentage of usable recycled materials that have been removed from the total amount of municipal solid waste generated in a specific area or by a specific business

**recycle/reuse** minimizing waste generation by recovering and reprocessing usable products that might otherwise become waste (recycling of aluminum cans, paper, and bottles, etc.)

**recycling mill** facility where recovered materials are remanufactured into new products

**redemption program** a program in which consumers are compensated for collection of recyclable materials, generally through prepaid deposits or taxes on beverage containers. In some states or localities legislation has enacted redemption programs to help prevent roadside litter

**red list** a list of species at an unusually high level of risk for extinction

**red tide** a proliferation of a marine plankton that are toxic to fish, perhaps stimulated by the addition of nutrients. A tide can be red, green, or brown, depending on the coloration of the plankton

**reduction** a chemical reaction that includes the addition of hydrogen, removal of oxygen, or addition of electrons to an element or compound

**reef** a wave-resistant ridge or mound built by corals or other marine invertebrate organisms

**reentry (in indoor air program)** refers to air exhausted from a building that is immediately drawn back into the system through the air intake and other openings

**reentry interval** the period immediately after the application of a pesticide during which unprotected workers should not enter a field

**reference dose (RfD)** a numerical estimate of a daily oral exposure to the human population, including sensitive subgroups such as children, that is not likely to cause harmful effects during a lifetime. RfDs are generally used for health effects that are thought to have a threshold or low dose limit for producing effects

**reflection** the bouncing and return or diversion of a wave that strikes a surface (interface)

**reformulated gasoline** gasoline with a different composition from conventional gasoline (i.e., lower aromatics content) that reduces air pollutants

**refraction** the bending of a wave when it changes velocity as it passes from one medium to another

**refueling emissions** emissions released during vehicle refueling

**refuse reclamation** conversion of solid waste into useful products (e.g., composting organic wastes to make soil conditioners or separating aluminum and other metals for recycling)

**Regional Response Team (RRT)** representatives of federal, local, and state agencies who may assist in coordination of activities at the request of the on-scene coordinator before and during a significant pollution incident such as an oil spill, major chemical release, or Superfund response.

**registrant** any manufacturer or formulator who obtains registration for a pesticide active ingredient or product

**registration** formal listing with the EPA of a new pesticide before it can be sold or distributed. Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA is responsible for registration (premarket licensing) of pesticides on the basis of data demonstrating no

unreasonable adverse effects on human health or the environment when applied according to approved label directions.

**Regulated Asbestos-Containing Material (RACM)** friable asbestos containing material (ACM) or nonfriable ACM subjected to sanding, grinding, cutting, or abrading or that has crumbled or been pulverized or reduced to powder during demolition or renovation operations

**regulated medical waste** under the Medical Waste Tracking Act of 1988, any solid waste generated in the diagnosis, treatment, or immunization of human beings or animals, in medical research, or in the production or testing of biologicals. Included are cultures and stocks of infectious agents, human blood and blood products, human pathological body wastes from surgery and autopsy, contaminated animal carcasses from medical research, waste from patients who have communicable diseases, and all used sharp implements, such as needles and scalpels, and certain unused sharps

**relative ecological sustainability** ability of an ecosystem to maintain its ecological integrity indefinitely

**relative permeability** the permeability of a rock to gas, NAPL, or water, when any two or more are present

**release** any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment of a hazardous or toxic chemical or extremely hazardous substance

**remedial action (RA)** the actual construction or implementation phase of a Superfund site cleanup that follows remedial design

**remedial design** a phase of remedial action that follows the remedial investigation/feasibility study (RI/FS) and includes development of engineering drawings and specifications for a site cleanup

**remedial investigation** an in-depth study designed to gather data needed to determine the nature and extent of contamination at a Superfund site, establish site cleanup criteria, identify preliminary alternatives for remedial action, and support technical and cost analyses of alternatives. The remedial investigation is usually done with the feasibility study. Together they are usually referred to as the RI/FS

**Remedial Project Manager (RPM)** the EPA or state official responsible for overseeing on-site remedial action. Sometimes referred to as the case manager

**remedial response** long-term action that stops or substantially reduces a release or threat of a



release of hazardous substances that is not an immediate threat to public health

**remediation** cleanup or other methods used to remove or contain a toxic spill or hazardous materials from a Superfund site

**remote sensing** the collection and interpretation of information about an object without physical contact with the object (e.g., satellite imaging, aerial photography, and open path measurements)

**removal action** short-term immediate actions taken to address releases of hazardous substances that require expedited response

**renewable resource** a natural resource that is virtually unlimited or that is replenished by the environment over relatively short periods

**reportable quantity (RQ)** quantity of a hazardous substance that triggers a reporting requirement under CERCLA. If a substance exceeds its RQ, the release must be reported to the National Response Center and community emergency coordinators for areas likely to be affected

**repowering** rebuilding and replacing major components of a power plant instead of building a new one

**representative sample** a portion of material or liquid that is as nearly identical in content and consistency as possible to that in the larger body of material or liquid being sampled

**reserve capacity** extra treatment capacity built into solid waste and wastewater treatment plants and interceptor sewers to accommodate flow increases due to future population growth

**reservoir** any natural or artificial holding area used to store, regulate, or control water

**residential use** pesticide application in and around houses, office buildings, apartment buildings, motels, and other living or working areas

**residential waste** all waste generated in single and multifamily homes other than those that are diverted to backyard composting

**residual** amount of a pollutant remaining in the environment after a natural or technological removal process, for example, particulate remaining in air after it passes through a bag-house filter

**residual risk** the extent of health risk from air pollutants remaining after application of the Maximum Achievable Control Technology (MACT)

**residual saturation** saturation level below which fluid drainage does not occur

**residue** the dry solids remaining after the evaporation of a sample of water or sludge

**resistance** for plants and animals, the ability to withstand poor environmental conditions or attacks by chemicals or disease

**resource recovery** the process of obtaining matter or energy from formerly discarded materials

**response action** term for actions taken in response to actual or potential health-threatening environmental events such as spills, sudden releases, and asbestos abatement/management problems. Also, a CERCLA-authorized action involving either a short-term removal action or a long-term removal response. This may include but is not limited to removing hazardous materials from a site to an EPA-approved hazardous waste facility for treatment, containing or treating the waste on-site, identifying and removing the sources of groundwater contamination, and halting further migration of contaminants

**responsiveness summary** a summary of oral and/or written public comments received by the EPA during a comment period on key EPA documents and the EPA's response to those comments

**restoration** measures taken to restore a site to pre-violation conditions

**restricted entry interval** the time after a pesticide application during which entry into the treated area is restricted

**restricted use pesticide (RUP)** a pesticide may be classified (under FIFRA regulations) for restricted use if it requires special handling because of its toxicity, and, if so, it may be applied only by trained, certified applicators or those under their direct supervision

**restriction enzymes** enzymes that recognize specific regions of a long deoxyribonucleic acid (DNA) molecule and cut it at those points

**retrofit** addition of a pollution control device on an existing facility without making major changes to the generating plant. Also called backfit

**reuse** using a product or component of municipal solid waste in its original form more than once (e.g., refilling a glass bottle that has been returned or using a coffee can to hold nuts and bolts)

**reverse osmosis** a treatment process used in water systems that adds pressure to force water through a semipermeable membrane. Reverse osmosis removes most drinking water contaminants. Also used in wastewater treatment

**reversible effect** a health effect that is not permanent; especially an adverse effect that diminishes when exposure to a toxic chemical stops

**ribonucleic acid (RNA)** a molecule that carries the genetic message from deoxyribonucleic acid (DNA) to a cellular protein-producing mechanism

- rill** a small channel eroded into the soil by surface runoff; can be easily smoothed out or obliterated by normal tillage
- Ringelmann chart** a chart containing a scale of shades/screens used to measure the opacity of air pollution emissions, ranging from light gray through black; used to set and enforce emissions standards
- riparian habitat** areas adjacent to rivers and streams with a differing density, diversity, and productivity of plant and animal species relative to nearby uplands
- riparian rights** entitlement of a landowner to certain uses of water on or bordering the property, including the right to prevent diversion or misuse of upstream waters; generally a matter of state law
- risk** a measure of the probability that damage to life, health, property, and/or the environment will result from a given activity
- risk assessment** qualitative and quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence and/or use of specific pollutants
- risk-based targeting** the direction of resources to those areas that have been identified as having the highest potential or actual adverse effect on human health and/or the environment
- risk characterization** the last phase of the risk assessment process that estimates the potential for adverse health or ecological effects from exposure to a stressor and evaluates the uncertainty involved
- risk communication** the exchange of information about health or environmental risks among risk assessors and managers, the general public, news media, interest groups, and others
- risk estimate** a description of the probability that organisms exposed to a specific dose of a chemical or other pollutant will develop an adverse response
- risk factor** characteristics (e.g., race, sex, age, obesity) or variables (e.g., smoking, occupational exposure level) associated with increased probability of a toxic effect
- risk management** the process of evaluating and selecting alternative regulatory and nonregulatory responses to risk. The selection process requires the consideration of legal, economic, and behavioral factors
- risk-specific dose** the dose associated with a specified risk level
- river basin** the land area drained by a river and its tributaries
- roasting** pretreatment of ore by heating to below its melting point, usually in the presence of air. This converts the ore into a chemical form more suitable for further processing
- rodenticide** a chemical or agent used to destroy rats or other rodent pests or to prevent them from damaging food, crops, and so on
- rotary kiln incinerator** an incinerator with a rotating combustion chamber that keeps waste moving, thereby allowing it to vaporize for easier burning
- route of exposure** the way a chemical has contact with an organism (e.g., inhalation, ingestion, dermal contact, injection)
- rubbish** solid waste, excluding food waste and ashes, from homes, institutions, and workplaces
- runoff** that part of precipitation, snowmelt, or irrigation water that flows over the land and enters streams or other surface water. It can sweep pollutants from the air and land into receiving waters
- sacrificial anode** an easily corroded material installed in a pipe or tank to prevent corrosion
- safe** condition of exposure under which there is a practical certainty that no harm to exposed individuals will result
- safener** a chemical added to a pesticide to prevent it from injuring plants
- safe yield** the annual amount of groundwater that can be taken from a source of supply (aquifer) over a period of years without depleting that source beyond its ability to be replenished naturally
- salinity** the percentage of salt in water
- salts** minerals made up of a cation from a base and an anion from an acid. Water picks up salt as it passes through the air, over and under the ground, or from households and industry
- salvage** the utilization of waste materials
- sampling frequency** the interval between the collections of successive samples
- sand filters** devices that remove some suspended solids from sewage. Air and bacteria decompose additional wastes filtering through the sand so that cleaner water drains from the filter
- sanitary sewers** underground pipes that carry away domestic or industrial waste but not storm water
- sanitary water (gray water)** water discharged from sinks, showers, kitchens, or other nonindustrial operations, but not from toilets
- sanitation** control of physical factors in the human environment that could harm development, health, or survival
- saprolite** a soft, clay-rich, thoroughly decomposed rock formed in place by chemical weathering of

rock. Forms in humid, tropical, or subtropical climates

**saprophytes** organisms living on dead or decaying organic matter that help natural decomposition of organic matter in water

**saturated zone** the area below the water table where all open spaces are filled with water

**saturation** the condition of a liquid when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure

**Science Advisory Board (SAB)** a group of external scientists who advise the EPA on science and policy

**scrap** materials discarded from manufacturing operations that may be suitable for reprocessing.

**scrap metal processor** intermediate operating facility where recovered metal is sorted, cleaned of contaminants, and prepared for recycling

**screening** use of screens to remove coarse floating and suspended solids from sewage

**screening risk assessment** a risk assessment performed with few data and many assumptions to identify exposures that should be evaluated more carefully for potential risk

**scrubber** an air pollution device that uses a spray of water or reactant or a dry process to trap pollutants in emissions

**secondary drinking water regulations** nonenforceable regulations that apply to public water systems and specify the maximum contamination levels that, in the judgment of the EPA, are required to protect the public welfare. These regulations apply to any contaminants that may adversely affect the odor or appearance of water and consequently may cause people served by the system to discontinue its use

**secondary effect** action of a stressor on supporting components of the ecosystem, which, in turn, impact the ecological component of concern

**secondary extraction** the removal of additional crude oil by using solvents or by flushing underground rocks with water or steam

**secondary materials** materials that have been manufactured and used at least once and are to be used again

**secondary standards** national ambient air quality standards designed to protect welfare, including effects on soils, water, crops, vegetation, synthetic (anthropogenic) materials, animals, wildlife, weather, visibility, and climate; damage to property; transportation hazards; economic values; and personal comfort and well-being

**secondary treatment** the second step in most publicly owned waste treatment systems, in which bacteria consume the organic parts of the waste. It is accomplished by collecting together waste, bacteria, and oxygen in trickling filters or in the activated sludge process. This treatment removes floating and settleable solids and about 90 percent of the oxygen-demanding substances and suspended solids. Disinfection is the final stage of secondary treatment

**sedimentation** letting solids settle out of wastewater by gravity during treatment

**sedimentation tanks** wastewater tanks in which floating wastes are skimmed off and settled solids are removed for disposal

**sediments** soil, sand, and minerals washed from land into water, usually after rain. They pile up in reservoirs, rivers, and harbors, destroying fish and wildlife habitat and clouding the water so that sunlight cannot reach aquatic plants. Careless farming, mining, and building activities expose sediment materials, allowing them to wash off the land after precipitation

**sediment yield** the quantity of sediment arriving at a specific location

**seed protectant** a chemical applied before planting to protect seeds and seedlings from disease or insects

**seepage** percolation of water through the soil from unlined canals, ditches, laterals, watercourses, or water storage facilities

**selective pesticide** a chemical designed to affect only certain types of pests, leaving other plants and animals unharmed

**semiconfined aquifer** an aquifer partially confined by soil layers of low permeability through which recharge and discharge can still occur

**semipermeable membrane** thin films of materials that allow only water and other small molecules to pass through them. Examples include the skins of fruit and vegetables

**semivolatile organic compound (SVOC)** organic compound that volatilizes slowly at standard temperature and pressure (20°C and 1 atm pressure)

**senescence** the aging process. Sometimes used to describe lakes or other bodies of water in advanced stages of eutrophication. Also used to describe plants and animals

**septic system** an on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a system of tile lines or a pit for disposal of the liquid effluent

- (sludge) that remains after decomposition of the solids by bacteria in the tank
- septic tank** an underground storage tank for wastes from homes not connected to a sewer line. Waste goes directly from the home to the tank
- service connector** the pipe that carries tap water from a public water main to a building
- service line sample** a 0.26-gallon (1-L) sample of water that has been standing for at least six hours in a service pipeline and is collected according to federal regulations
- service pipe** the pipeline extending from the water main to the building served or to the consumer's system
- settlable solids** material heavy enough to sink to the bottom of a wastewater treatment tank
- settling chamber** a series of screens placed in the way of flue gases to slow the stream of air, thus helping gravity to pull particles into a collection device
- settling tank** a holding area for wastewater, where heavier particles sink to the bottom for removal and disposal
- seven-day, consecutive low flow with a 10-year return frequency (7Q10)** the lowest stream flow for seven consecutive days that would be expected to occur once in 10 years
- sewage** the waste and wastewater produced by residential and commercial sources and discharged into sewers
- sewage sludge** sludge produced at a Publicly Owned Treatment Works, the disposal of which is regulated under the Clean Water Act
- sewer** a channel or conduit that carries wastewater and storm-water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both
- shading coefficient** the amount of the Sun's heat transmitted through a given window compared with that of a standard 1/8-inch-thick single pane of glass under the same conditions
- sharps** hypodermic needles, syringes (with or without the attached needle), Pasteur pipettes, scalpel blades, blood vials, needles with attached tubing, and culture dishes used in animal or human patient care or treatment or in medical, research, or industrial laboratories. Also included are other types of broken or unbroken glassware that had contact with infectious agents, such as used slides and coverslips and unused hypodermic and suture needles, syringes, and scalpel blades
- shelterbelt** a row of trees or other tall perennial vegetation placed along the edges of farm fields to slow wind speeds and reduce erosion
- shock load** the unanticipated arrival at a water treatment plant of raw water containing unusual amounts of algae, colloidal matter, suspended solids, turbidity, or other pollutants
- short-circuiting** occurs when some of the water in tanks or basins flows faster than the rest; may result in shorter contact, reaction, or settling times than calculated or presumed and not allow for adequate treatment
- sick building syndrome** condition of a building whose occupants experience acute health and/or comfort effects that appear to be linked to time spent therein, but where no specific illness or cause can be identified. Complaints may be localized in a particular room or zone or may spread throughout the building
- signal words** the words used on a pesticide label—*Danger*, *Warning*, *Caution*—to indicate level of toxicity
- significant deterioration** pollution resulting from a new source in previously uncontaminated areas
- significant municipal facilities** those publicly owned sewage treatment plants that discharge 1 million gallons (3.8 million L) per day or more and are therefore considered by states to have the potential to affect the quality of receiving waters substantially
- significant potential source of contamination** a facility or activity that stores, uses, or produces compounds with potential for significant contaminating impact if released into the source water of a public water supply
- significant violations** violations by point source dischargers of sufficient magnitude or duration to be a regulatory priority
- silt** sedimentary materials composed of fine-sized particles
- silviculture** management of forestland for timber
- single-breath canister** small 1-liter canister designed to capture a single breath. Used in air pollutant ingestion research
- sink** a place in the environment where a compound or material collects
- sinking** controlling oil spills by using an agent to trap the oil and force it to the bottom of the body of water, where the agent and the oil are biodegraded
- SIP Call** under the Clean Air Act, an EPA action requiring a state to resubmit all or part of its State Implementation Plan (SIP) to demonstrate



attainment of the required national ambient air quality standards within the statutory deadline

**site** an area or place within the jurisdiction of the EPA and/or a state where a release to the environment has or may have occurred

**Site Assessment Program** a means of evaluating hazardous waste sites through preliminary assessments and site inspections to develop a Hazard Ranking System score

**site inspection** the collection of information from a Superfund site to determine the extent and severity of hazards posed by the site. It follows and is more extensive than a preliminary assessment. The purpose is to gather information necessary to score the site, using the Hazard Ranking System, and to determine whether it presents an immediate threat requiring prompt removal

**siting** the process of choosing a location for a facility, usually involving extensive public input

**skimming** using a machine to remove floating oil or scum from the surface of the water

**slow sand filtration** passage of raw water through a bed of sand at low velocity, resulting in substantial removal of chemical and biological contaminants

**sludge** a semisolid residue from any of a number of air or water treatment processes; can be a hazardous waste

**sludge digester** tank in which complex organic substances such as sewage sludge are biologically dredged. During these reactions, energy is released and much of the sewage is converted to methane, carbon dioxide, and water

**slurry** a watery mixture of insoluble matter resulting from some pollution control techniques

**small-quantity generator (SQG);** sometimes referred to as Squeegee; persons or enterprises that produce 220–2,200 pounds (100–1,000 kg) per month of hazardous waste

**smelter** a facility that melts or fuses ore, often with accompanying chemical change, to separate its metal content. Emissions cause pollution

**smog** air pollution typically associated with oxidants

**smoke** particles suspended in air after incomplete combustion

**soft detergents** cleaning agents that biodegrade when released into the environment

**soft water** water that does not contain a significant amount of dissolved minerals such as salts of calcium or magnesium

**soil adsorption field** a subsurface area containing a trench or bed with clean stones and a system of piping through which treated sewage may seep into the surrounding soil for further treatment and disposal

**soil and water conservation practices** control measures consisting of managerial, vegetative, and structural practices to reduce the loss of soil and water

**soil conditioner** an organic material such as humus or compost that helps soil absorb water, build a bacterial community, and take up mineral nutrients

**soil erodibility** an indicator of a soil's susceptibility to raindrop impact, runoff, and other erosive processes

**soil gas** gaseous elements and compounds in the small spaces between particles of the earth and soil. Such gases can be moved or driven out under pressure

**soil moisture** the water contained in the pore space of soil in the unsaturated zone

**soil sterilant** a chemical that temporarily or permanently prevents the growth of all plants and animals

**solder** metallic compound used to seal joints between pipes. Until recently, most solder contained 50 percent lead. Use of solder containing more than 0.2 percent lead in pipes carrying drinking water is now prohibited

**sole-source aquifer** an aquifer that supplies 50 percent or more of the drinking water of an area

**solidification and stabilization** physical encapsulation or chemical alteration of a waste to make it less permeable and susceptible to transport by water

**solid waste** nonliquid, nonsoluble materials ranging from municipal garbage to industrial wastes that contain complex and sometimes hazardous substances. Solid wastes also include sewage sludge, agricultural refuse, demolition wastes, and mining residues. It also can include liquids and gases in containers

**solid waste disposal** the final placement of refuse that is not salvaged or recycled

**solid waste management** supervised handling of waste materials from their source through recovery processes to disposal

**solubility** the amount of mass of a compound that will dissolve in a unit volume of solution. Aqueous solubility is the maximal concentration of a chemical that will dissolve in pure water at a reference temperature

**solute** any substance being dissolved into a solution. Solutes are usually present in lesser quantities than the solvent

**solution** a homogeneous mixture of a solute in a carrying fluid (solvent) such as water

**solvent** the component of a solution that is present in the largest quantity. In aqueous systems, the solvent is water

**soot** carbon dust formed by incomplete combustion  
**sorption** the action of attracting substances by electrochemical means; process used in many pollution control systems

**source area** the location of liquid hydrocarbons or the zone of highest soil or groundwater concentrations of the chemical of concern

**source characterization measurements** measurements made to estimate the rate of release of pollutants into the environment from a source such as an incinerator or landfill

**source reduction** reducing the amount of materials entering the waste stream from a specific source by redesigning products or patterns of production or consumption (e.g., using returnable beverage containers)

**source separation** segregating various wastes at the point of generation (e.g., separation of paper, metal, and glass from other wastes to make recycling simpler and more efficient)

**sparge or sparging** injection of air below the water table to strip dissolved volatile organic compounds and/or oxygenate groundwater to facilitate aerobic biodegradation of organic compounds

**special waste** items such as household hazardous waste, bulky wastes (refrigerators, pieces of furniture, etc.), tires, and used oil

**species** a reproductively isolated aggregate of interbreeding organisms having common attributes and usually designated by a common name

**specific conductance** rapid method of estimating the dissolved solids content of a water supply by testing its capacity to carry an electrical current

**specific yield** the amount of water a unit volume of saturated permeable rock will yield when drained by gravity

**Spill Prevention, Containment, and Countermeasures Plan (SPCP)** plan describing actions to be taken in the event of a release of hazardous substances as defined in the Clean Water Act

**spoil** dirt or rock removed from its original location, destroying the composition of the soil in the process, as in strip-mining, dredging, or construction

**sprawl** unplanned development of open land

**spray tower scrubber** a device that sprays alkaline water into a chamber where acid gases are present to aid in neutralizing the gas

**spring** groundwater seeping out of the earth at a point where the water table intersects the ground surface

**spring melt/thaw** the process whereby warm temperatures melt winter snow and ice. Because various forms of acid deposition may have been stored

in the frozen water, the melt can result in the entry of abnormally large amounts of acidity into streams and rivers, sometimes causing fish kills

**stabilization** conversion of the active organic matter in sludge into inert, harmless material

**stabilization ponds** See LAGOON

**stable air** a motionless mass of air that retains, instead of dispersing, pollutants.

**stack** a chimney, smokestack, or vertical pipe that discharges used air

**stack effect** air, as in a chimney, that moves upward because it is warmer and consequently less dense than the ambient atmosphere. Also, the flow of air resulting from warm air rising, creating a positive pressure area at the top of a building and negative pressure area at the bottom. This effect can overpower the mechanical system and disrupt building ventilation and air circulation

**stack gas** See FLUE GAS

**Stage II Controls** systems placed on service station gasoline pumps to control and capture gasoline vapors during refueling

**stagnation** lack of motion in a mass of air or water that holds pollutants in place

**stakeholder** any organization, governmental entity, or individual that has an interest in or may be impacted by a given approach to environmental regulation, pollution prevention, energy conservation, or other action

**Standard Industrial Classification Code** also known as SIC Code, a method of grouping industries with similar products or services and assigning codes to these groups

**standards** norms that impose limits on the amount of pollutants or emissions produced. The EPA establishes minimal standards; states are allowed to be more strict

**standard sample** the part of finished drinking water that is examined for the presence of coliform bacteria

**State Implementation Plans (SIP)** EPA-approved state plans for the establishment, regulation, and enforcement of air pollution standards

**static water depth** the vertical distance from the centerline of the pump discharge down to the surface level of the well or standing water body. Measured while no water is being withdrawn from the water table

**static water level** elevation or level of the water table in a well when the pump is not operating. Also, the level or elevation to which water would rise in a tube connected to an artesian aquifer or basin in a conduit under pressure

**stationary source** a fixed-site producer of air pollution, mainly power plants and other facilities using industrial combustion processes

**sterilization** the removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms, and spores

**sterilizer** one of three groups of antimicrobials registered by the EPA for public health uses. The EPA considers an antimicrobial material to be a sterilizer if it destroys or eliminates all forms of bacteria, viruses, and fungi and their spores. Spores are considered the most difficult form of microorganism to destroy, and the EPA considers the term *sporicide* to be synonymous with *sterilizer*

**storage** temporary holding of waste pending treatment or disposal, as in containers, tanks, waste piles, and surface impoundments

**storm sewer** a system of pipes (separate from sanitary sewers) that carries water runoff from buildings and land surfaces

**stratigraphy** study of the formation, composition, and sequence of rocks and sediments, whether consolidated or not

**stratosphere** the portion of the atmosphere 10–25 miles (160–400 km) above the Earth's surface

**stressors** physical, chemical, or biological entities that can induce adverse effects on ecosystems or human health

**strip-cropping** growing crops in a systematic arrangement of strips or bands that serve as barriers to wind and water erosion

**strip-mining** a process that uses machines to scrape soil or rock away from mineral deposits just below the Earth's surface

**structural deformation** distortion in walls of a tank after liquid has been added or removed

**subchronic** of intermediate duration, usually used to describe studies or periods of exposure lasting between five and 90 days

**subchronic exposure** multiple or continuous exposures lasting for approximately 10 percent of an experimental species' lifetime, usually over a three-month period

**sublimation** the direct conversion of a solid to a gas without first changing to a liquid

**submerged aquatic vegetation** vegetation that lives at or below the water surface; an important habitat for young fish and other aquatic organisms

**substance** matter that cannot be separated into component parts by a physical process

**subwatershed** topographic perimeter of the catchment area of a stream tributary

**succession** a change in the composition and structure of an ecosystem as the available competing organisms respond to and modify the environment

**sump** a below-grade level pit or tank that catches liquid runoff for drainage or disposal

**superchlorination** chlorination with doses that are deliberately selected to produce water free of combined residuals so large as to require dechlorination

**supercritical water** a type of thermal treatment using moderate temperatures and high pressures to enhance the ability of water to break down large organic molecules into smaller, less toxic ones. Oxygen injected during this process combines with simple organic compounds to form carbon dioxide and water

**Superfund Innovative Technology Evaluation (SITE) Program** an EPA program to promote development and use of innovative treatment and site characterization technologies in Superfund site cleanups

**surface impoundment** a below-land surface pond or basin used for the treatment, storage, or disposal of liquid hazardous wastes

**surface runoff** precipitation, snowmelt, or irrigation water in excess of that which can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants in rivers, streams, and lakes

**surface water** all water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.)

**Surface-Water Treatment Rule** rule that specifies maximal contaminant level goals for *Giardia lamblia*, viruses, and *Legionella* with filtration and disinfection requirements for public water systems using surface-water or groundwater sources under the direct influence of surface water. The regulations also specify water quality, treatment, and watershed protection criteria

**surfacing ACM** asbestos-containing material that is sprayed or troweled on or otherwise applied to surfaces, such as acoustical plaster on ceilings and fireproofing materials on structural members

**surfacing material** material sprayed or troweled onto structural members (beams, columns, or decking) for fire protection; or on ceilings or walls for fireproofing, acoustical, or decorative purposes. Includes textured plaster and other textured wall and ceiling surfaces

**surfactant** a detergent compound that promotes lathering (formation of suds)

**surrogate data** data from studies of test organisms or a test substance that are used to estimate the characteristics of or effects on a related organism or substance

**surveillance system** a series of monitoring devices designed to check on environmental conditions

**susceptibility analysis** an analysis to determine whether a public water supply is subject to significant pollution from known potential sources

**suspect material** building material suspected of containing asbestos (e.g., surfacing material, floor tile, ceiling tile, thermal system insulation)

**suspended loads** specific sediment particles maintained in the water column by turbulence and carried with the flow of water

**suspended solids** small particles of solid pollutants that float on the surface of, or are suspended in, sewage or other liquids. They resist removal by conventional means

**suspension culture** cells growing in a liquid nutrient medium

**sustainable development (sustainability)** the use of renewable and nonrenewable natural resources in a manner that satisfies current economic and societal needs without compromising the availability of these resources for future generations

**swamp** a type of wetland dominated by woody vegetation but without appreciable peat deposits. Swamps may be freshwater or salt water and tidal or nontidal

**symbiosis** mutualistic relationship of different species that live close together

**synergism** an interaction of two or more chemicals that results in an effect greater than the sum of their separate effects

**synthetic organic chemicals (SOCs)** anthropogenic organic chemicals. Some SOC are volatile; others tend to stay dissolved in water instead of evaporating

**system** in ecology, a network of interacting and interconnected physical, biological, and chemical relationships

**systemic pesticide** a chemical absorbed by an organism that interacts with the organism and makes it toxic to pests

**system with a single service connection** a system that supplies drinking water to consumers via a single service line

**tailings** residue of raw material or waste separated out during the processing of crops or mineral ores

**tailpipe standards** emission limitations applicable to mobile source engine exhausts

**tail water** the runoff of irrigation water from the lower end of a field

**tar sands** sand deposits containing heavy petroleum compound (bitumen) that is too thick to

be pumped. Tar sands are excavated and heated with steam to separate the bitumen and allow its processing into usable petroleum products

**Technical Assistance Grant (TAG)** as part of the Superfund program, Technical Assistance Grants of up to \$50,000 are provided to citizens' groups to obtain assistance in interpreting information related to cleanups at Superfund sites or those proposed for the National Priorities List. Grants are used by such groups to hire technical advisers to help them understand the site-related technical information for the duration of response activities

**technology-based limitations** industry-specific wastewater limits based on best available preventive technology applied to a discharge when it will not cause a violation of water quality standards at low stream flows. Usually applied to discharges into large rivers

**technology-based standards** industry-specific wastewater limits applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water-quality effects

**teratogen** a substance capable of causing birth defects

**teratogenesis** the introduction of nonhereditary birth defects in a developing fetus by exogenous factors such as physical or chemical agents acting in the womb that interfere with normal embryonic development

**terracing** the practice of building walls or dikes along the contour of sloping farmland that hold runoff and sediment to reduce erosion

**tertiary treatment** advanced cleaning of wastewater that goes beyond the secondary or biological stage, removing nutrients such as phosphorus, nitrogen, and most biological oxygen demand (BOD) and suspended solids

**theoretical maximum residue contribution (TMRC)** the theoretical maximal amount of a pesticide in the daily diet of an average person. It assumes that the diet is composed of all food items for which there are tolerance-level residues of the pesticide. The TMRC is expressed as milligrams of pesticide per kilograms of body weight per day

**therapeutic index** the ratio of the dose required to produce toxic or lethal effects to the dose required to produce nonadverse or therapeutic response

**thermal pollution** discharge of heated water from industrial processes that can kill or injure aquatic organisms

**thermal stratification** the formation of layers of different temperatures in a lake or reservoir



**thermal system insulation (TSI)** asbestos-containing material applied to pipes, fittings, boilers, breeching, tanks, ducts, or other interior structural components to prevent heat loss or gain or water condensation

**thermal treatment** use of elevated temperatures to treat hazardous wastes

**thermochemistry** the study of the relationship between heat and chemical reactions

**thermocline** the middle layer of a thermally stratified lake or reservoir. In this layer, there is a rapid decrease in temperatures in a lake or reservoir

**threshold** the dose or exposure level below which a significant adverse effect is not expected

**threshold level** time-weighted average pollutant concentration values, exposure beyond which is likely to adversely affect human health

**threshold limit value (TLV)** the concentration of an airborne substance to which an average person can be repeatedly exposed without adverse effects. TLVs may be expressed as either TLV-TWA (time-weighted average), based on an allowable exposure averaged over a normal eight-hour workday or 40-hour workweek; or TLV-STEL (short-term exposure limit), the maximum concentration for a brief specified period, depending on a specific chemical; or TLV-C (ceiling exposure limit), the maximum exposure concentration not to be exceeded under any circumstances

**Threshold Planning Quantity** a quantity designated for each chemical on the list of extremely hazardous substances that triggers notification by facilities to the State Emergency Response Commission that such facilities are subject to emergency planning requirements under SARA Title III

**tidal marsh** low, flat marshlands traversed by channels and tidal hollows, subject to tidal inundation; normally, the only vegetation present are salt-tolerant bushes and grasses

**time-weighted average (TWA)** in air sampling, the average air concentration of contaminants during a given period

**tolerances** permissible residue levels for pesticides in raw agricultural produce and processed foods. Whenever a pesticide is registered for use on a food or a feed crop, a tolerance (or exemption from the tolerance requirement) must be established. The EPA establishes the tolerance levels, which are enforced by the Food and Drug Administration and the Department of Agriculture

**tonnage** the amount of waste that a landfill accepts, usually expressed in tons per month.

The rate at which a landfill accepts waste is limited by the landfill's permit

**topsoil** that portion of the soil that is most supportive of plant growth and is very important for ecosystem sustainability and agriculture

**total dissolved phosphorus** the total phosphorus content of all material that will pass through a filter, which is determined as orthophosphate without prior digestion or hydrolysis

**total dissolved solids (TDS)** all solid material that passes through a 2-micron-size sieve or filter. Term is used to reflect hardness

**Total Maximum Daily Load (TMDL)** a calculation of the highest amount of a pollutant that a water body can receive and safely meet water quality standards set by the state, territory, or authorized tribe

**total petroleum hydrocarbons (TPH)** measure of the concentration or mass of petroleum hydrocarbon constituents present in a given amount of soil or water

**total recovered petroleum hydrocarbon** a method for measuring petroleum hydrocarbons in samples of soil or water

**total suspended particles (TSP)** a method of monitoring airborne particulate matter by total weight

**total suspended solids (TSS)** a measure of the suspended solids (of a specified size) in wastewater, effluent, or water bodies

**toxicant** a harmful substance or agent that may injure an exposed organism

**toxic chemical** any chemical listed in the EPA rules as Toxic Chemicals Subject to Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986

**Toxic Chemical Release Form** information form required of facilities that manufacture, process, or use chemicals listed under SARA Title III

**toxic chemical use substitution** replacing toxic chemicals with less harmful chemicals in industrial processes

**toxic cloud** airborne plume of gases, vapors, fumes, or aerosols containing toxic materials

**toxic concentration** the concentration at which a substance produces a toxic effect

**toxic dose** the dose level at which a substance produces a toxic effect

**toxicity** the degree to which a substance or mixture of substances can harm humans or animals. ACUTE TOXICITY involves harmful effects in an organism through a single or short-term exposure. CHRONIC TOXICITY is the ability of a substance or mixture of substances to cause harmful effects over an extended period, usually

upon repeated or continuous exposure, sometimes lasting for the entire life of the exposed organism. **SUBCHRONIC TOXICITY** is the ability of the substance to cause effects for more than one year but less than the lifetime of the exposed organism

**toxicity assessment** characterization of the toxicological properties and effects of a chemical, with special emphasis on establishment of dose-response characteristics

**toxicity testing** biological testing (usually with an invertebrate, fish, or small mammal) to determine the adverse effects of a compound or wastewater

**toxicological profile** an examination, summary, and interpretation of a hazardous substance to determine levels of exposure and associated health effects

**toxic pollutants** materials that cause death, disease, or birth defects in organisms that ingest or absorb them. The quantities and exposures necessary to cause these effects can vary widely

**toxic release inventory (TRI)** database of toxic releases in the United States compiled from SARA Title III Section 313 reports

**toxic substance** a chemical or mixture that may present an unreasonable risk of injury to health or the environment

**toxic waste** a waste that can produce injury if inhaled, swallowed, or absorbed through the skin

**transboundary pollutants** air pollution that travels from one jurisdiction to another, often crossing state or international boundaries. Also applies to water pollution

**transfer station** facility where solid waste is transferred from collection vehicles to larger trucks or railcars for longer-distance transport. Limited processing of waste (compaction, bailing) also may occur at these sites.

**transient water system** a noncommunity water system that does not serve 25 of the same non-residents per day for more than six months per year

**transmission lines** pipelines that transport raw water from its source to a water treatment plant, then to the distribution grid system

**transmissivity** the ability of an aquifer to transmit water

**transpiration** the process by which water vapor is lost to the atmosphere from living plants

**transportation control measures (TCMs)** steps taken by a locality to reduce vehicular emission and improve air quality by reducing or changing the flow of traffic (e.g., bus and HOV lanes, car-

pooling and other forms of ride sharing, public transit, bicycle lanes)

**transporter** hauling firm that picks up properly packaged and labeled hazardous waste from generators and transports it to designated facilities for treatment, storage, or disposal. Transporters are subject to EPA and DOT hazardous waste regulations

**trash** material considered worthless or offensive that is thrown away. Generally defined as dry waste material, but in common usage it is a synonym for garbage, rubbish, or refuse

**trash-to-energy plan** burning trash to produce energy

**treatability studies** tests of potential cleanup technologies conducted in a laboratory

**treated regulated medical waste** medical waste that has been treated to reduce substantially or eliminate its pathogenicity but that has not yet been destroyed

**treated wastewater** wastewater that has been subjected to one or more physical, chemical, and biological processes to reduce its potential as a health hazard

**treatment** any method, technique, or process designed to remove solids and/or pollutants from solid waste, waste streams, effluents, and air emissions. Also, methods used to change the biological character or composition of any regulated medical waste to reduce substantially or eliminate its potential for causing disease

**treatment plant** a structure built to treat wastewater before discharging it into the environment

**Treatment, Storage, and Disposal Facility (TSD, TSDF)** a site where a hazardous substance is treated, stored, or disposed. TSD facilities are regulated by EPA and states under RCRA

**trial burn** an incinerator test in which emissions are monitored for the presence of specific organic compounds, particulates, and hydrogen chloride

**tributary** any surface water body that contributes water to a stream or river

**trickle irrigation** method in which water drips to the soil from perforated tubes or emitters

**trickling filter** a treatment system in which wastewater is trickled or sprinkled over a bed of stones or other material covered with bacteria that break down the organic waste and produce clean water

**trihalomethane (THM)** one of a family of organic compounds named as derivatives of methane. THMs are generally by-products of chlorination of drinking water that contains organic material

**trophic levels** a functional classification of species that is based on feeding relationships (e.g., generally aquatic and terrestrial green plants

compose the first trophic level, and herbivores compose the second

**troposphere** the layer of the atmosphere closest to the Earth's surface

**trust fund (CERCLA)** a fund set up under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) to help pay for cleanup of hazardous waste sites and for legal action to force those responsible for the sites to clean them up

**tsunami** a large sea wave produced by a submarine earthquake, landslide, or volcano

**tuberculation** development or formation of small mounds of corrosion products on the inside of iron pipe. These tubercles roughen the inside of the pipe, increasing its resistance to water flow

**tube settler** device using bundles of tubes to let solids in water settle to the bottom for removal by conventional sludge collection means; sometimes used in sedimentation basins and clarifiers to improve particle removal

**turbidimeter** a device that measures the cloudiness of suspended solids in a liquid; a measure of the quantity of suspended solids

**turbidity** haziness in air caused by the presence of particles and pollutants. In water quality measurements, a cloudy condition in water due to suspended silt or organic matter

**turnover** a process occurring in fall and spring in some lakes where deep, cold water rises to the surface and warmer, near-surface water moves to the bottom. Turnover is an important mechanism in the replenishment of dissolved oxygen and distribution of nutrients throughout the water column

**ultraclean coal (UCC)** coal that is washed, ground into fine particles, and chemically treated to remove sulfur, ash, silicone, and other substances; usually briquetted and coated with a sealant; generates very low emissions when burned

**ultraviolet rays** UV rays from one part of the spectrum (UV-A) enhance plant life. UV rays from other parts of the spectrum (UV-B) can cause skin cancer or other tissue damage. The ozone layer in the atmosphere partly shields the Earth's surface from ultraviolet rays

**uncertainty** related to precision. Measurements of high precision have low uncertainty

**uncertainty factor (UF)** one of several factors used in calculating the reference dose from experimental data. UFs are intended to account for the variation in sensitivity among humans, the uncertainty in extrapolating animal data to humans, the uncertainty in extrapolating data

obtained in a study that covers less than the full life of the exposed animal or human, and the uncertainty in using LOAEL data rather than NOAEL data

**unconfined aquifer** an aquifer containing water that is not under pressure; the water level in a well is the same as the level of the water table outside the well

**Underground Injection Control (UIC)** the program under the Safe Drinking Water Act that regulates the use of wells to pump fluids into the ground

**underground injection wells** steel- and concrete-encased shafts into which hazardous waste is deposited by force and under pressure

**underground mine** a mine consisting of subterranean passages that commonly follow ore veins or coal seams

**underground sources of drinking water** aquifers currently being used as a source of drinking water or those capable of supplying a public water system. They have a total dissolved solids content of 10,000 milligrams per liter or less

**unreasonable risk** any unjustifiable risk to people or the environment, taking into account the medical, economic, social, and environmental costs and benefits of any pesticide or chemical product

**unsaturated zone** the area above the water table where soil pores are not fully saturated, although some water may be present

**upper detection limit** the largest concentration that an instrument can reliably detect

**upslope fog** fog that forms when air cools as it flows along a land surface that is increasing in elevation

**upwelling** a rising ocean current that transports water from the depths toward the surface

**uranium mill tailings piles** former uranium ore processing sites that contain radioactive materials (wastes), including radium and unrecovered uranium

**uranium mill tailings waste piles** licensed active mills with tailings piles and evaporation ponds created by acid or alkaline leaching processes

**urban runoff** storm water from city streets and adjacent domestic or commercial properties that carries pollutants of various kinds into the sewer systems and receiving waters

**urea-formaldehyde foam insulation** a material once used to conserve energy by sealing crawl spaces, attics, and so on, and no longer used because emissions were found to be a health hazard

- use cluster** a set of competing chemicals, processes, and/or technologies that can substitute for each other in performing a particular function
- used oil** spent motor oil from passenger cars and trucks collected at specified locations for recycling (not included in the category of municipal solid waste)
- utility load** the total electricity demand for a utility district
- vadose zone** the zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric. Soil pore space also typically contains air or other gases. The capillary fringe is included in the vadose zone
- valued environmental attributes/components** those aspects (components, processes, or functions) of ecosystems, human health, and environmental welfare considered to be important and potentially at risk from human activity or natural hazards. Similar to the term *valued environmental components* used in Environmental Impact Assessment
- van der Waals forces** weak, intermolecular forces operating between small molecules that holds them together; a type of chemical bonding or attraction
- vapor** the gas given off by substances that are solids or liquids at ordinary atmospheric pressure and temperatures
- vapor capture system** any combination of hoods and ventilation systems that captures or contains vapors so they may be directed to an abatement or recovery device
- vapor dispersion** the movement of vapor clouds in air due to wind, thermal action, gravity spreading, and mixing
- vapor plumes** flue gases visible because they contain water droplets
- vapor pressure** a measure of a substance's propensity to evaporate. Vapor pressure is the force per unit area exerted by vapor in an equilibrium state with surroundings at a given pressure. It increases exponentially with an increase in temperature. Also a relative measure of chemical volatility, vapor pressure is used to calculate water partition coefficients and volatilization rate constants
- vapor recovery system** a system by which the volatile gases from gasoline storage and handling are captured instead of being released into the atmosphere
- variance** government permission for a delay or exception in the application of a given law, ordinance, or regulation
- vector** an organism, often an insect or rodent, that carries disease. Also, plasmids, viruses, or bacteria used to transport genes into a host cell. A gene is placed in the vector; the vector then infects the bacterium
- vegetative controls** nonpoint source pollution control practices that involve vegetative cover to reduce erosion and minimize migration of pollutants
- ventilation rate** the rate at which indoor air enters and leaves a building. Expressed as the number of changes of outdoor air per unit of time (air changes per hour [ACH]) or the rate at which a volume of outdoor air enters at a given rate (e.g., cubic feet per minute [CFM])
- ventilation/suction** the act of admitting fresh air into a space in order to replace stale or contaminated air; achieved by blowing air into the space. Similarly, suction represents the admission of fresh air into an interior space by lowering the pressure outside the space, thereby drawing the contaminated air outward
- venturi scrubbers** air pollution control devices that use water to remove particulate matter from emissions
- virgin materials** resources extracted from nature in their raw form, such as timber or metal ore
- viscosity** the molecular friction within a fluid that produces flow resistance
- volatile** any substance that evaporates readily
- volatile liquids** liquids that readily vaporize or evaporate at room temperature
- volatile solids** those solids in water or other liquids that are lost on ignition of the dry solids at 550°C
- volatile synthetic organic chemicals (VSOCs)** synthesized chemicals that tend to volatilize or evaporate
- volume reduction** processing waste materials to decrease the amount of space they occupy, usually by compacting, shredding, incineration, or composting
- volumetric tank test** one of several tests to determine the physical integrity of a storage tank. The volume of fluid in the tank is measured directly or calculated from product-level changes. A marked drop in volume over a specified period indicates a leak
- vulnerability analysis** assessment of elements in the community that are susceptible to damage if hazardous materials are released



**vulnerable zone** an area over which the concentration of a chemical accidentally released could reach the level of concern

**waste** unwanted materials left over from a manufacturing process. Also, refuse from places of human or animal habitation

**waste characterization** identification of chemical and microbiological constituents of a waste material

**waste exchange** arrangement in which companies exchange their wastes for the benefit of both parties

**waste feed** the continuous or intermittent flow of wastes into an incinerator

**waste generation** the weight or volume of materials and products that enter the waste stream before recycling, composting, landfilling, or combustion takes place. Also can represent the amount of waste generated by a given source or category of sources

**waste-heat recovery** recovering heat discharged as a by-product of one process to provide heat needed by a second process

**waste load allocation** the maximum amount of pollutants each discharger of waste is allowed to release into a particular waterway. Discharge limits are usually required for each specific water quality criterion that is or expected to be violated. Also, the portion of a stream's total assimilative capacity assigned to an individual discharge

**waste minimization** measures or techniques that reduce the amount of wastes generated during industrial production processes; term is also applied to recycling and other efforts to reduce the amount of waste entering the waste stream

**waste piles** noncontainerized, lined, or unlined accumulations of solid, nonflowing waste

**waste reduction** using source reduction, recycling, or composting to prevent or reduce waste generation

**waste stream** the total flow of solid waste from homes, businesses, institutions, and manufacturing plants that is recycled, burned, or disposed of in landfills

**waste-to-energy facility/municipal-waste combustor** facility where recovered municipal solid waste is converted into a usable form of energy, usually via combustion

**waste treatment lagoon** impoundment made by excavation of soil for biological treatment of wastewater

**waste treatment plant** a facility containing a series of tanks, screens, filters, and other processes by which pollutants are removed from water

**wastewater** the spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter

**wastewater infrastructure** the plan or network for the collection, treatment, and disposal of sewage in a community. The level of treatment depends on the size of the community, the type of discharge, and/or the designated use of the receiving water

**wastewater operations and maintenance** actions taken after construction to ensure that facilities developed to treat wastewater will be operated, maintained, and managed to achieve prescribed levels in an optimal manner

**wastewater treatment plan** a facility containing a series of tanks, screens, filters, and other processes by which pollutants are removed from water. Most treatments include chlorination to attain safe drinking water standards

**waterborne disease outbreak** the significant occurrence of acute illness associated with drinking water from a public water system that is deficient in treatment, as determined by appropriate local or state agencies

**water purveyor** a public utility, mutual water company, county water district, or municipality that delivers drinking water to customers

**water quality-based limitations** limitations applied to dischargers when technology-based limitations would cause violations of water quality standards. Usually applied to discharges into small streams

**water quality-based permit** a permit with an effluent limit more stringent than one based on technology performance. Such limits may be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply)

**water quality criteria** levels of water quality expected to render a body of water suitable for its designated use. Criteria are based on specific levels of pollutants that make the water harmful if used for drinking, swimming, irrigation, fish production, or industrial processes

**water quality standards** state-adopted and EPA-approved ambient standards for water bodies. The standards prescribe the use of the water body and establish the water quality criteria that must be met to protect designated uses

**watershed** the land area that drains into a stream. The watershed for a major river may encompass a number of smaller watersheds that ultimately combine at a common point

**watershed approach** a coordinated framework for environmental management that focuses public and private efforts on the highest-priority

problems within hydrologically defined geographic areas, taking into consideration both groundwater and surface water flow

**water solubility** the maximum possible concentration of a chemical compound dissolved in water. If a substance is water-soluble, it can very readily disperse through the environment

**water-soluble packaging** packaging that dissolves in water; used to reduce exposure risks to pesticide mixers and loaders

**water-source heat pump** heat pump that uses wells or heat exchangers to transfer heat from water to the inside of a building. Most such units use groundwater

**water storage pond** an impoundment for liquid wastes designed to accomplish some degree of biochemical treatment

**water supplier** one who owns or operates a public water system

**water supply system** the collection, treatment, storage, and distribution of potable water from source to consumer

**water table** the level of groundwater in an aquifer or other water-bearing zone. The upper surface of groundwater at the top of the zone of saturation and below the zone of aeration

**water treatment lagoon** an impoundment for liquid wastes designed to accomplish some degree of biochemical treatment

**water well** an excavation where the intended use is for location, acquisition, development, or artificial recharge of groundwater.

**wave** a periodic disturbance in a medium that is described by specifying its amplitude, speed, wavelength, and frequency

**wave height** the vertical distance from the crest to the trough of a wave

**wavelength** the distance from one crest or trough of a wave to the next

**weight of scientific evidence** considerations in assessing the interpretation of published information about toxicity—quality of testing methods, size, and power of study design, consistency of results across studies, and biological plausibility of exposure-response relationships and statistical associations

**weir** a wall or plate placed in an open channel to measure the flow of water. Also, a wall or obstruction used to control flow from settling tanks and clarifiers to ensure a uniform flow rate and prevent short-circuiting

**well field** area containing one or more wells that produce usable amounts of water or oil

**wellhead protection area** a protected surface and subsurface zone surrounding a well or well field supplying a public water system. Land use

in these areas is restricted or tightly regulated in order to prevent contaminants from reaching the well water

**well injection** the subsurface forcing of fluids into a well

**well monitoring** measurement of well water quality by on-site instruments or laboratory methods

**well plug** a watertight, gastight seal installed in a borehole or well to prevent movement of fluids

**well point** a hollow vertical tube, rod, or pipe terminating in a perforated pointed shoe or bit and fitted with a fine-mesh screen

**wettability** the relative degree to which a fluid will spread into or coat a solid surface in the presence of other immiscible fluids

**wettable powder** dry formulation that must be mixed with water or other liquid before it is applied

**wheeling** the transmission of electricity owned by one entity through the facilities owned by another (usually a utility)

**whole-effluent-toxicity tests** tests to determine the toxicity levels of the total effluent from a single source, as opposed to a series of tests for individual contaminants

**wildlife refuge** an area designated for the protection of wild animals, within which hunting and fishing are either prohibited or strictly controlled

**wind turbine** a mechanical device that converts the wind's kinetic energy (energy of motion) into electrical energy

**wood-burning-stove pollution** air pollution caused by emissions of particulate matter, carbon monoxide, total suspended particulates, and polycyclic organic matter from wood-burning stoves

**wood treatment facility** an industrial facility that treats lumber and other wood products for outdoor use. The process employs chromated copper arsenate, which is regulated as a hazardous material

**working level (WL)** a unit of measure for documenting exposure to radon decay products. One working level is equal to approximately 200 picocuries per liter

**working level month (WLM)** a unit of measure used to determine cumulative exposure to radon

**yellow-boy** iron oxide flocculent (clumps of solids in waste or water); usually observed as orange-yellow deposits in surface streams with excess iron content. Commonly associated with acid mine drainage

**yield** the quantity of water (expressed as a rate of flow or total quantity per year) that can be collected for a given use from surface water or groundwater sources

**zero air** atmospheric air purified to contain less than 0.1 part per million (ppm) total hydrocarbons

**zero emission vehicles** private and public transportation devices, typically powered by electricity, that have no direct emissions

**zone of aeration** a subsurface zone above the water table that may be moist but not saturated. It lies above the zone of saturation

**zone of saturation** the layer beneath the surface of the land containing openings that may fill with water

**zoning** the organization or partitioning of land areas for various types of usage in cities, boroughs, or townships

**zooplankton** small (often microscopic) free-floating aquatic plants or animals

# APPENDIX IV

## FURTHER RESOURCES

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# APPENDIX V

## 2007 CERCLA PRIORITY LIST OF HAZARDOUS SUBSTANCES

Note: The following CERCLA Priority List of Hazardous Substances is prepared by the U.S. Environmental Protection Agency using relevant toxicology and abundance documentation, and it is distributed by the Agency for Toxic Substances and Disease Registry (ATSDR) of the U.S. Department of Health and Human Services. The rankings are accurate as of January 2011.

2007 Rank	Substance Name	2005 Rank
1	Arsenic	1
2	Lead	2
3	Mercury	3
4	Vinyl Chloride	4
5	Polychlorinated Biphenyls (PCB)	5
6	Benzene	6
7	Cadmium	8
8	Polycyclic Aromatic Hydrocarbons (PAH)	7
9	Benzo(A)Pyrene (PAH)	9
10	Benzo(B)Fluoranthene (PAH)	10
11	Chloroform	11
12	DDT, P,P'-	12
13	Aroclor 1254 (PCB)	13
14	Aroclor 1260 (PCB)	14
15	Dibenzo(A,H)Anthracene (PAH)	15
16	Trichloroethylene (TCE)	16
17	Dieldrin	17
19	Phosphorus, White	19
18	Chromium, Hexavalent	18
20	Chlordane	21
21	DDE, P,P'-	20
22	Hexachlorobutadiene (HCB)	22

2007 Rank	Substance Name	2005 Rank
23	Coal Tar Creosote	23
24	Aldrin	25
25	DDD, P,P'-	24
26	Benzidine	26
27	Aroclor 1248 (PCB)	27
28	Cyanide	28
29	Aroclor 1242 (PCB)	29
30	Aroclor (PCB)	62
31	Toxaphene	30
32	Hexachlorocyclohexane, Gamma- (HCH)	32
33	Tetrachloroethylene (PCE)	31
34	Heptachlor	33
35	1,2-Dibromoethane	34
36	Hexachlorocyclohexane, Beta- (HCH)	37
37	Acrolein	36
38	Disulfoton	35
39	Benzo(A)Anthracene (PAH)	38
40	3,3'-Dichlorobenzidine (DCB)	39
41	Endrin	41
42	Beryllium	40
43	Hexachlorocyclohexane, Delta- (HCH)	42
44	1,2-Dibromo-3-Chloropropane (DBCP)	43
45	Pentachlorophenol (PCP)	45
46	Heptachlor Epoxide	44
47	Carbon Tetrachloride	46
48	Aroclor 1221 (PCB)	47
49	Cobalt	50
50	DDT, O,P'-	49
51	Aroclor 1016 (PCB)	48
52	Di-N-Butyl Phthalate (Phthalate)	52
53	Nickel	55
54	Endosulfan	54
55	Endosulfan Sulfate	53
56	Diazinon	57
57	Endosulfan, Alpha	58
58	Xylenes, Total	59
59	Cis-Chlordane	51

2007 Rank	Substance Name	2005 Rank
60	Dibromochloropropane (DBCP)	60
61	Methoxychlor	61
62	Benzo(K)Fluoranthene (PAH)	63
63	Endrin Ketone	64
64	Trans-Chlordane	56
65	Chromium(VI) Oxide	66
66	Methane	67
67	Endosulfan, Beta	65
68	Aroclor 1232 (PCB)	68
69	Endrin Aldehyde	69
70	Benzofluoranthene (PAH)	70
71	Toluene	71
72	2-Hexanone (MBK)	72
73	2,3,7,8-Tetrachlorodibenzo-P-Dioxin (Dioxin)	73
74	Zinc	74
75	Dimethylarsinic Acid	75
76	Di(2-Ethylhexyl)Phthalate (Phthalate)	76
77	Chromium	77
78	Naphthalene	78
79	1,1-Dichloroethene (DCE)	79
80	Methylene Chloride	81
81	Aroclor 1240	80
82	2,4,6-Trinitrotoluene (TNT)	82
83	Bromodichloroethane (BDA)	83
84	Hydrazine	85
85	1,2-Dichloroethane (DCA)	84
86	2,4,6-Trichlorophenol (TCP)	86
87	2,4-Dinitrophenol	87
88	Bis(2-Chloroethyl) Ether	88
89	Thiocyanate	89
90	Asbestos	90
91	Chlorine	92
92	Cyclotrimethylenetrinitramine (RDX)	91
93	Hexachlorobenzene (HCB)	93
94	2,4-Dinitrotoluene (DNT)	96
95	Radium 226	94
96	Ethion	97



2007 Rank	Substance Name	2005 Rank
97	1,1,1-Trichloroethane (TCA)	95
98	Uranium	98
99	Ethylbenzene	99
100	Radium	100
101	Thorium	101
102	4,6-Dinitro-O-Cresol	102
103	1,3,5-Trinitrobenzene	103
104	Chlorobenzene	105
105	Radon	104
106	Radium 228	106
107	Thorium 230	107
107	Uranium 235	107
109	Barium	109
110	Fluoranthene (PAH)	113
111	Uranium 234	110
112	N-Nitrosodi-N-Propylamine	111
113	Thorium 228	112
114	Radon 222	114
115	Hexachlorocyclohexane, Alpha- (HCH)	116
116	1,2,3-Trichlorobenzene (TCB)	143
117	Manganese	115
118	Coal Tars	117
119	Chrysotile Asbestos	119
119	Strontium 90	119
121	Plutonium 239	118
122	Polonium 210	122
123	Methylmercury	121
124	Plutonium 238	123
125	Lead 210	124
126	Plutonium	125
127	Chlorpyrifos	125
128	Copper	133
129	Americium 241	128
130	Radon 220	127
131	Amosite Asbestos	129
132	Iodine 131	130

2007 Rank	Substance Name	2005 Rank
133	Hydrogen Cyanide	132
134	Tributyltin	131
135	Guthion	134
136	Neptunium 237	135
137	Chrysene	139
138	Chlordecone	136
138	Iodine 129	136
138	Plutonium 240	136
141	S,S,S-Tributyl Phosphorotrithioate	140
142	Bromine	142
143	Polybrominated Biphenyls (PBB)	141
144	Dicofol	144
145	Parathion	145
146	1,1,2,2-Tetrachloroethane (PCA)	146
147	Selenium	147
148	Hexachlorocyclohexane, Technical Grade (HCH)	148
149	Trichlorofluoroethane	149
150	Trifluralin	150
151	DDD, O,P'-	151
152	4,4'-Methylenebis(2-Chloroaniline)	152
153	Hexachlorodibenzo-P-Dioxin (Dioxin)	153
154	Heptachlorodibenzo-P-Dioxin (Dioxin)	154
155	Pentachlorobenzene	155
156	1,3-Butadiene	201
157	Ammonia	156
158	2-Methylnaphthalene	157
159	1,4-Dichlorobenzene (DCB)	159
160	1,1-Dichloroethane (DCA)	158
161	Acenaphthene	160
162	1,2,3,4,6,7,8,9-Octachlorodibenzofuran (Furan)	161
163	1,1,2-Trichloroethane (TCA)	162
164	Trichloroethane (TCA)	163
165	Hexachlorocyclopentadiene (HC)	164
166	Heptachlorodibenzofuran (Furan)	165
167	1,2-Diphenylhydrazine	166
168	2,3,4,7,8-Pentachlorodibenzofuran (Furan)	167

2007 Rank	Substance Name	2005 Rank
169	Tetrachlorobiphenyl	168
170	Cresol, Para-	169
171	Oxychlordane	170
172	1,2-Dichlorobenzene (DCB)	171
173	1,2-Dichloroethene, Trans-	178
174	Indeno(1,2,3-Cd)Pyrene (PAH)	180
175	Gamma-Chlordene	172
176	Carbon Disulfide	174
177	Tetrachlorophenol	173
178	Americium	175
178	Uranium 233	175
180	Palladium	177
181	Hexachlorodibenzofuran (Furan)	179
182	Phenol	183
183	Chloroethane	182
184	Acetone	181
185	P-Xylene	185
186	Dibenzofuran (Furan)	187
187	Aluminum	186
188	2,4-Dimethylphenol	189
189	Carbon Monoxide	188
190	Tetrachloroethane (PCA)	190
191	Hydrogen Sulfide	193
192	Pentachlorodibenzofuran (Furan)	192
193	Chloromethane	191
194	Bis(2-Methoxyethyl) Phthalate (Phthalate)	194
195	Butyl Benzyl Phthalate (Phthalate)	195
196	Cresol, Ortho-	196
197	Hexachloroethane	199
198	Vanadium	198
199	N-Nitrosodimethylamine	200
200	1,2,4-Trichlorobenzene (TCB)	203
201	Bromoform	202
202	Tetrachlorodibenzo-P-Dioxin (Dioxin)	204
203	1,3-Dichlorobenzene (DCB)	205
204	Pentachlorodibenzo-P-Dioxin (Dioxin)	207

2007 Rank	Substance Name	2005 Rank
205	N-Nitrosodiphenylamine	208
206	1,2-Dichloroethylene (DCE)	206
207	2,3,7,8-Tetrachlorodibenzofuran (Furan)	210
208	2-Butanone (MEK)	209
209	2,4-Dichlorophenol	212
210	1,4-Dioxane	215
211	Fluorine	214
212	Nitrite	216
213	Cesium 137	217
214	Silver	213
215	Chromium Trioxide	218
216	Nitrate	219
217	Potassium 40	220
218	Dinitrotoluene (DNT)	221
219	Antimony	222
220	Coal Tar Pitch	224
221	Thorium 227	223
222	2,4,5-Trichlorophenol	225
223	Arsenic Acid	226
224	Arsenic Trioxide	227
225	Phorate	228
226	Benzopyrene (PAH)	230
227	Cresols	229
228	Chlordane, Technical	231
229	Dimethoate	232
230	Actinium 227	233
231	Strobane	233
232	4-Aminobiphenyl	235
233	Pyrethrum	235
234	Arsine	237
235	Naled	238
236	Dibenzofurans, Chlorinated	239
237	Ethoprop	239
238	Alpha-Chlordene	241
239	Carbophenothion	241
240	Dichlorvos	243



2007 Rank	Substance Name	2005 Rank
241	Calcium Arsenate	244
242	Mercuric Chloride	244
243	Sodium Arsenite	244
244	Formaldehyde	247
245	2-Chlorophenol	248
246	Phenanthrene	249
247	Hydrogen Fluoride	250
248	2,4-D Acid	251
249	Dibromochloromethane	252
250	Diuron	253
251	Butylate	254
252	Dimethyl Formamide	255
253	Pyrene	256
254	Dichlorobenzene	211
255	Ethyl Ether	257
256	Dichloroethane	258
257	4-Nitrophenol	259
258	1,3-Dichloropropene, Cis-	184
259	Phosphine	260
260	Trichlorobenzene	261
261	2,6-Dinitrotoluene	262
262	Fluoride Ion	263
263	1,2,3,4,6,7,8-Heptachlorodibenzo-P-Dioxin (Dioxin)	264
264	Methyl Parathion	265
265	Pentaerythritol Tetranitrate	266
266	1,3-Dichloropropene, Trans-	267
267	Bis(2-Ethylhexyl)Adipate	268
268	Carbazole	269
269	Methyl Isobutyl Ketone (MIK)	271
270	1,2-Dichloroethene, Cis-	270
271	Styrene	272
272	Carbaryl	273
273	1,2,3,4,6,7,8-Heptachlorodibenzofuran (Furan)	274
274	Acrylonitrile	275
275	1-Methylnaphthalene	New

# APPENDIX VI

## EPA TOXICS RELEASE INVENTORY (TRI) FOR INDUSTRIAL POLLUTANTS RELEASED TO THE ENVIRONMENT BY ALL INDUSTRIES IN THE UNITED STATES

Monitored Industrial Chemicals	2009 Total Reported Releases of Industrial Chemicals (in pounds [kg])	2007 Total Reported Releases of Industrial Chemical (in pounds [kg])
1,1,1,2-Tetrachloroethane	3,689 (1,677)	2,249 (1,022)
1,1,1-Trichloroethane	108,310 (49,232)	81,479 (37,036)
1,1,2,2-Tetrachloroethane	4,505 (2,048)	1,861(846)
1,1,2-Trichloroethane	16,980 (7,718)	22,367 (10,167)
1,2-Dichloroethylene	6,097 (2,771)	4,399 (2,000)
1,2-Dichloropropane	104,501 (47,500)	115,710 (52,595)
1,3-Butadiene	1,175,585 (534,357)	1,788,084 (812,765)
1,3-Dichlorobenzene	152 (69)	1,827 (830)
1,4-Dichlorobenzene	27,753 (12,615)	79,266 (36,030)
1,4-Dioxane	250,767 (113,985)	185,132 (84,151)
2,4-Dichlorophenol	27,246 (12,385)	13,541(6,155)
2,4-Dinitrotoluene	132,060 (60,027)	13,594 (6,179)
2,6-Dinitrotoluene	2,559 (1,163)	1,343 (610)
4,6-Dinitro-O-Cresol	2 (1)	104 (47)
Acrolein	566,732 (257,605)	1,696,876 (771,307)
Alachlor	7,583 (3,447)	373 (140)
Aldrin	2,149 (977)	1,128 (513)
Aniline	1,080,390 (491,350)	920,606 (418,457)
Anthracene	46,663 (21,210)	171,896 (78,135)
Antimony	979,545 (445,248)	1,312,688 (596,676)
Antimony Compounds	12,042,242 (5,473,746)	11,013,365 (5,006,075)
Arsenic	747,985 (339,766)	3,201,986 (1,455,448)
Arsenic Compounds	95,353,933 (43,342,697)	94,379,174 (42,899,625)
Asbestos (Friable)	8,757,577 (3,980,717)	10,430,381 (4,741,082)

Monitored Industrial Chemicals	2009 Total Reported Releases of Industrial Chemicals (in pounds [kg])	2007 Total Reported Releases of Industrial Chemical (in pounds [kg])
Atrazine	872,465 (396,575)	515,072 (234,124)
Barium	5,101,144 (2,318,702)	8,243,367 (3,746,985)
Barium Compounds	237,066,763 (107,757,620)	236,593,707 (107,542,593)
Benzene	4,062,618 (1,846,645)	8,465,367 (3,847,894)
Benzidine	12 (5.5)	16 (7.3)
Benzo(G,H,I)Perylene	53,083 (24,129)	98,286 (44,675)
Beryllium	10,425 (4,739)	14,185 (7,093)
Beryllium Compounds	710,830 (323,105)	852,894 (387,679)
Bifenthrin	11,471 (5,214)	4 (1.8)
Biphenyl	379,989 (172,722)	4,800,703 (2,182,138)
Cadmium	402,730 (183,059)	935,512 (935,512)
Cadmium Compounds	2,113,739 (960,790)	2,971,879 (1,350,854)
Calcium Cyanamide	13 (5.9)	127 (58)
Carbaryl	628 (285)	847 (385)
Carbofuran	7,520 (3,418)	391 (178)
Carbon Tetrachloride	152,480 (72,036)	308,357 (140,162)
Chlordane	2,939 (1,336)	6,353 (2,888)
Chlorobenzene	211,894 (96,315)	545,708 (248,049)
Chloroform	553,148 (251,431)	706,555 (321,161)
Chromium	7,948,749 (3,613,068)	11,769,410 (5,349,732)
Chromium Compounds (except Chromite Ore Mined in the Transvaal Region)	36,406,436 (16,548,380)	48,633,079 (22,105,945)
Cobalt	297,451 (135,205)	875,292 (397,860)
Cobalt Compounds	5,493,942 (2,497,246)	6,095,001 (2,770,455)
Creosote	499,660 (227,118)	1,950,641 (886,655)
Cresol (Mixed Isomers)	1,920,535 (872,970)	1,240,288 (563,767)
Cyanide Compounds	4,649,726 (2,113,512)	6,871,538 (3,123,426)
Diazinon	204 (93)	2,194 (997)
Dibenzofuran	11,260 (5,118)	17,440 (7,927)
Dibutyl Phthalate	211,963 (96,347)	335,487 (152,494)
Diisocyanates	4,391,699 (1,996,227)	1,472,453 (669,297)
Dimethyl Phthalate	173,962 (79,074)	287,316 (130,598)
Dioxin and Dioxin-Like Compounds	71 (32)	319 (145)
Ethylbenzene	3,249,340 (1,476,973)	4,843,102 (2,201,410)

Monitored Industrial Chemicals	2009 Total Reported Releases of Industrial Chemicals (in pounds [kg])	2007 Total Reported Releases of Industrial Chemical (in pounds [kg])
Ethylene	16,097,555 (7,317,070)	18,577,924 (8,444,511)
Formaldehyde	14,577,081 (6,625,946)	21,933,684 (9,969,856)
Freon 113	407,145 (185,066)	565,482 (257,037)
Heptachlor	2,203 (1,001)	1,133 (515)
Hexachloro-1,3-Butadiene	702 (319)	934 (425)
Hydrazine	11,842 (5,383)	16,759 (7,618)
Lead	14,281,724 (6,491,693)	20,940,344 (9,518,338)
Lead Compounds	382,183,216 (173,719,644)	474,935,219 (215,879,644)
Lindane	236 (107)	1,555 (707)
M-Cresol	156,150 (70,977)	192,773 (87,624)
Mercury	123,481 (56,281)	101,984 (46,356)
Mercury Compounds	6,011,831 (2,732,650)	6,833,638 (3,106,199)
Methoxychlor	2,440 (1,109)	1,050 (477)
Methyl Tert-Butyl Ether	325,209 (147,822)	585,465 (266,120)
Naphthalene	1,357,697 (617,135)	2,850,878 (1,295,854)
Nickel	5,131,571 (2,332,532)	8,212,983 (3,733,174)
Nickel Compounds	23,740,670 (10,791,214)	29,689,094 (13,495,042)
Nitrate Compounds	241,545,741 (109,793,519)	270,689,909 (123,040,864)
O-Cresol	36,105 (16,411)	20,118 (9,145)
O-Xylene	176,062 (80,028)	325,496 (147,953)
Ozone	605 (275)	704,712 (320,324)
P-Cresol	77,741 (35,337)	104,857 (47,662)
P-Xylene	944,211 (429,187)	1,311,540 (596,155)
Pentachlorobenzene	905 (411)	1,464 (665)
Pentachlorophenol	146,572 (66,624)	2,740 (1,245)
Phenol	6,323,008 (2,874,095)	6,677,767 (3,035,349)
Phosgene	13,317 (6,053)	15,290 (6,950)
Phosphorus (Yellow or White)	135,308 (61,504)	276,993 (125,906)
Polychlorinated Biphenyls	3,236,241 (1,471,019)	2,090,371 (950,169)
Polycyclic Aromatic Compounds	907,596 (412,544)	1,365,384 (620,629)
Selenium	142,762 (64,892)	1,443,711 (656,232)
Selenium Compounds	2,731,929 (1,241,786)	2,843,232 (1,292,378)
Sodium Nitrite	2,581,274 (1,173,309)	4,320,241 (1,963,746)
Styrene	19,972,424 (9,078,375)	40,748,666 (18,522,120)



Monitored Industrial Chemicals	2009 Total Reported Releases of Industrial Chemicals (in pounds [kg])	2007 Total Reported Releases of Industrial Chemical (in pounds [kg])
Styrene Oxide	32 (15)	466 (212)
Tetrachloroethylene	1,534,082 (697,310)	2,237,864 (1,017,211)
Toluene	29,051,423 (13,177,505)	41,716,513 (18,962,051)
Toluene-2,4-Diisocyanate	4,923 (2,238)	18,955 (8,616)
Toluene-2,6-Diisocyanate	1,357 (617)	3,795 (1,725)
Toxaphene	2,495 (1,134)	1,212 (551)
Trichloroethylene	2,882,252 (1,310,115)	4,485,202 (2,038,728)
Vinyl Chloride	390,531 (177,514)	372,635 (169,380)
Vinylidene Chloride	42,110 (19,141)	57,013 (25,915)
Xylene (Mixed Isomers)	14,531,035 (6,605,016)	25,595,670 (1,163,440)
Zinc (Fume or Dust)	11,910,295 (5,413,770)	69,014,216 (31,370,098)
Zinc Compounds	781,13,597 (355,056,181)	731,304,206 (332,411,003)

# APPENDIX VII

## EPA DRINKING WATER STANDARDS

### INORGANIC CHEMICALS

Category	Maximum Amount (parts per million)	Body Part Affected/Disease	Sources
Antimony (Sb)	0.006	Blood	Oil refineries, ceramics, solder
Arsenic (As)	0.005	Skin, nervous system, cancer risk	Pesticide residue, industrial and smelter waste, rocks
Asbestos	0.7	Intestines	Cement decay, deposits
Barium (Ba)	1	Heart, gastrointestinal tract, nerves, muscles	Coal power plants, jet fuels, rocks, bricks, tiles
Beryllium (Be)	0.004	Intestines	Refineries, electronics, defense industry
Cadmium (Cd)	0.01	Kidneys, blood, liver	Mining, smelting, fuel, fertilizer, rocks
Chromium (Cr)	0.05	Liver, kidneys	Mines, rocks, electronics
Copper (Cu)	1.3	Liver, kidneys, gastrointestinal tract	Plumbing, natural deposits
Cyanide	0.2	Nerves, thyroids	Discharge from steel/metal factories and plastic and fertilizer factories
Fluoride	4	Bones	Additive to water, tooth-paste, foods
Mercury (Hg)	0.002	Nervous system, kidneys	Paint, paper, vinyl, fungicide, rocks
Nitrate (Nitrogen [N])	10	Blood, cancer risk	Fertilizer, sewage, rocks
Nitrite (Nitrogen [N])	1	Blood, cancer risk	Fertilizer, sewage, rocks
Selenium (Se)	0.01	Gastrointestinal tract	Coal, refineries, glass, plants, fuel oil, rocks
Silver (Ag)	0.05	Skin	Mining, rocks
Thallium (Tl)	0.0005	Hair loss, blood, kidneys, intestines, liver	Electronics, glass, drug factories, leachate

(continues)

## ORGANIC CHEMICALS

Category	Maximum Amount (parts per million)	Body Part Affected/Disease	Sources
Alachlor	0.002	Eye, liver, kidney, or spleen; anemia, cancer risks	Runoff from herbicide used on row crops
Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops
Benzene	0.005	Anemia, decrease in blood platelets, increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills
Benzo(a)pyrene (PAH)s	0.0002	Reproductive difficulties, increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	0.005	Liver problems, increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	0.002	Liver, nervous system problems, increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	Liver, kidneys	Discharge from chemical and agricultural chemical factories
2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	Kidney	Runoff from herbicide
1,2-Dibromo-3-chloropropane (DBCP)	0.0002	Reproductive difficulties, increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	Liver, kidney, circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	Anemia, liver, kidney, spleen, blood	Discharge from industrial chemical factories
1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories
1,1-Dichloroethylene	0.007	Liver	Discharge from industrial chemical factories
cis-1,2-Dichloroethylene	0.07	Liver	Discharge from industrial chemical factories
trans-1,2-Dichloroethylene	0.1	Liver	Discharge from industrial chemical factories
Dichloromethane	0.005	Liver problems, increased risk of cancer	Discharge from drug and chemical factories

**ORGANIC CHEMICALS** *(continued)*

Category	Maximum Amount (parts per million)	Body Part Affected/Disease	Sources
1,2-Dichloropropane	0.005	Cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl) adipate	0.4	Weight loss, liver problems, or possible reproductive difficulties	Discharge from chemical factories
Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties, liver problems, increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables
Dioxin (2,3,7,8-TCDD)	0.0000003	Reproductive difficulties, increased risk of cancer	Emissions from waste incineration and other combustion, discharge from chemical factories
Diquat	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	Gastrointestinal tract	Runoff from herbicide use
Endrin	0.002	Liver	Residue of banned insecticide
Ethylbenzene	0.7	Liver, kidneys	Discharge from petroleum refineries
Ethylene dibromide	0.00005	Liver, stomach, reproductive system, kidneys; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	Kidney problems, reproductive difficulties	Runoff from herbicide use
Heptachlor	0.0004	Liver damage, increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	0.0002	Liver damage, increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	0.001	Liver, kidneys, reproductive system; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	Kidneys, stomach	Discharge from chemical factories
Lindane	0.0002	Liver, kidneys	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	Nervous system	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs)	0.0005	Skin, thymus gland, immune system, reproductive, and nervous systems; increased risk of cancer	Runoff from landfills, discharge of waste chemicals

*(continues)*



**ORGANIC CHEMICALS** *(continued)*

Category	Maximum Amount (parts per million)	Body Part Affected/Disease	Sources
Polychlorinated biphenyls (PCBs)	0.0005	Skin, thymus gland, immune system, reproductive, and nervous systems; increased risk of cancer	Runoff from landfills, discharge of waste chemicals
Pentachlorophenol	0.001	Liver, kidneys; increased cancer risk	Discharge from wood-preserving factories
Picloram	0.5	Liver	Herbicide runoff
Simazine	0.004	Blood	Herbicide runoff
Styrene	0.1	Liver, kidneys, circulatory system	Discharge from rubber and plastic factories
Tetrachloroethylene	0.005	Liver, increased risk of cancer	Discharge from factories and dry cleaners
Toluene	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories
Toxaphene	0.003	Kidney, liver, thyroid; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	Liver	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	Adrenal glands	Discharge from textile finishing factories
1,1,1-Trichloroethane	0.20	Liver, nervous system, circulatory problems	Discharge from metal degreasing sites and other factories
1,1,2-Trichloroethane	0.003	Liver, kidneys, immune system	Discharge from industrial chemical factories
Trichloroethylene	0.005	Liver problems, increased risk of cancer	Discharge from metal degreasing sites and other factories
Vinyl chloride	0.002	Increased risk of cancer	Leaching from PVC pipes, discharge from plastic factories
Xylenes (total)	10	Nervous system	Discharge from petroleum factories, discharge from chemical factories

# APPENDIX VIII

## CURRENT NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS) FOR ALL CONTROLLED POLLUTANTS

ORGANIC CHEMICALS			
Pollutant	Primary Standards	Averaging Times	Secondary Standards
Carbon Monoxide	9 ppm (10 mg/m <sup>3</sup> )	8 hour <sup>a</sup>	None
	35 ppm (40 mg/m <sup>3</sup> )	1 hour <sup>a</sup>	None
Lead	1.5 mcg/m <sup>3</sup>	Quarterly Average	Same as Primary
Nitrogen Dioxide	0.053 ppm (100 mcg/m <sup>3</sup> )	Annual (Arithmetic Mean)	Same as Primary
Particulate Matter (PM <sup>10</sup> )	50 mcg/m <sup>3</sup>	Annual <sup>b</sup> (Arithmetic Mean)	Same as Primary
	150 mcg/m <sup>3</sup>	24 hour <sup>a</sup>	Same as Primary
Particulate Matter (PM <sup>2.5</sup> )	15.0 mcg/m <sup>3</sup>	Annual <sup>c</sup> (Arithmetic Mean)	Same as Primary
	65 mcg/m <sup>3</sup>	24 hour <sup>d</sup>	Same as Primary
Ozone	0.08 ppm	8 hour <sup>e</sup>	Same as Primary
	0.12 ppm	1 hour <sup>f</sup> (Applies only in limited areas)	Same as Primary
Sulfur Oxides	0.03 ppm	Annual (Arithmetic Mean)	—
	0.14 ppm	24 hour <sup>a</sup>	—
	—	3 hour <sup>a</sup>	0.5 ppm (1300 mcg/m <sup>3</sup> )

Notes:

<sup>a</sup> Not to be exceeded more than once per year.

<sup>b</sup> To attain this standard, the three-year average of the weighted annual mean PM<sub>10</sub> concentration at each monitor within an area must not exceed 50 mcg/m<sup>3</sup>.

<sup>c</sup> To attain this standard, the three-year average of the weighted annual mean PM<sub>2.5</sub> concentrations from single or multiple community-oriented monitors must not exceed 15.0 mcg/m<sup>3</sup>.

<sup>d</sup> To attain this standard, the three-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 65 mcg/m<sup>3</sup>.

<sup>e</sup> To attain this standard, the three-year average of the fourth-highest daily maximal eight-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.

<sup>f</sup> (a) The standard is attained when the expected number of days per calendar year with maximal hourly average concentrations above 0.12 ppm is less than one day. (b) As of June 15, 2005, EPA revoked the one-hour ozone standard in all areas except the 14 eight-hour ozone nonattainment Early Action Compact (EAC) areas.

# APPENDIX IX

## NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH (NIOSH) LIST OF IMMEDIATELY DANGEROUS TO LIFE AND HEALTH (IDLH) VALUES FOR CONTROLLED CHEMICALS

Substance	IDLH Value
Acetone	2,500 ppm
Acrolein	2 ppm
Aldrin	25 mg/m <sup>3</sup>
Allyl alcohol	20 ppm
Ammonia	300 ppm
Antimony compounds (as Sb)	50 mg Sb/m <sup>3</sup>
Arsenic (inorganic compounds, as As)	5 mg As/m <sup>3</sup>
Barium (soluble compounds, as Ba)	50 mg Ba/m <sup>3</sup>
Benzene	500 ppm
Beryllium compounds (as Be)	4 mg/m <sup>3</sup>
Bromine	3 ppm
1,3-Butadiene	2,000 ppm
tert-Butyl chromate	15 mg Cr(VI)/m <sup>3</sup>
Cadmium dust (as Cd)	9 mg Cd/m <sup>3</sup>
Cadmium fume (as Cd)	9 mg Cd/m <sup>3</sup>
Calcium arsenate (as As)	5 mg As/m <sup>3</sup>
Carbaryl	100 mg/m <sup>3</sup>
Carbon black	1,750 mg/m <sup>3</sup>
Carbon dioxide	40,000 ppm
Carbon monoxide	1,200 ppm
Carbon tetrachloride	200 ppm
Chlordane	100 mg/m <sup>3</sup>
Chlorobenzene	1,000 ppm
Chromic acid and chromates	15 mg Cr(VI)/m <sup>3</sup>
Chromium (II) compounds [as Cr(II)]	250 mg Cr(II)/m <sup>3</sup>
Chromium (III) compounds [as Cr(III)]	25 mg Cr(III)/m <sup>3</sup>

Substance	IDLH Value
Chromium metal (as Cr)	250 mg Cr/m <sup>3</sup>
Coal tar pitch volatiles	80 mg/m <sup>3</sup>
Cobalt metal, dust and fume (as Co)	20 mg Co/m <sup>3</sup>
Copper, dusts and mists (as Cu)	100 mg Cu/m <sup>3</sup>
Copper fume (as Cu)	100 mg Cu/m <sup>3</sup>
Cresol (o, m, p isomers)	250 ppm
Cyanides (as CN)	25 mg/m <sup>3</sup>
DDT	500 mg/m <sup>3</sup>
Dibutyl phthalate	4,000 mg/m <sup>3</sup>
o-Dichlorobenzene	200 ppm
p-Dichlorobenzene	150 ppm
1,1-Dichloroethane	3,000 ppm
1,2-Dichloroethylene	1,000 ppm
Dieldrin	50 mg/m <sup>3</sup>
Dimethylphthalate	2,000 mg/m <sup>3</sup>
Dinitroocresol	5 mg/m <sup>3</sup>
Dinitrotoluene	50 mg/m <sup>3</sup>
Di sec-octyl phthalate	5,000 mg/m <sup>3</sup>
Endrin	2 mg/m <sup>3</sup>
Ethyl benzene	800 ppm
Formaldehyde	20 ppm
Heptachlor	35 mg/m <sup>3</sup>
Hexachloroethane	300 ppm
Hexachloronaphthalene	2 mg/m <sup>3</sup>
Hydrazine	50 ppm
Hydrogen chloride	50 ppm
Hydrogen cyanide	50 ppm
Hydrogen selenide (as Se)	1 ppm
Hydrogen sulfide	100 ppm
Lead compounds (as Pb)	100 mg Pb/m <sup>3</sup>
Lindane	50 mg/m <sup>3</sup>
Lithium hydride	0.5 mg/m <sup>3</sup>
Mercury compounds [except (organo) alkyls, as Hg]	10 mg Hg/m <sup>3</sup>
Mercury (organo) alkyl compounds(as Hg)	2 mg Hg/m <sup>3</sup>
Methoxychlor	5,000 mg/m <sup>3</sup>



Substance	IDLH Value
Methyl chloride	2,000 ppm
Methylene chloride	2,300 ppm
Methyl isocyanate	3 ppm
Methyl styrene	700 ppm
Naphtha (coal tar)	1,000 ppm
Naphthalene	250 ppm
Nickel carbonyl (as Ni)	2 ppm
Nickel metal and other compounds (as Ni)	10 mg Ni/m <sup>3</sup>
Nicotine	5 mg/m <sup>3</sup>
Nitrogen dioxide	20 ppm
Oil mist (mineral)	2,500 mg/m <sup>3</sup>
Ozone	5 ppm
Pentachloronaphthalene	Unknown
Pentachlorophenol	2.5 mg/m <sup>3</sup>
Phenol	250 ppm
Phosgene	2 ppm
Phosphorus (yellow)	5 mg/m <sup>3</sup>
Phosphorus pentachloride	70 mg/m <sup>3</sup>
Phosphorus pentasulfide	250 mg/m <sup>3</sup>
Phosphorus trichloride	25 ppm
Phthalic anhydride	60 mg/m <sup>3</sup>
Selenium compounds (as Se)	1 mg Se/m <sup>3</sup>
Selenium hexafluoride	2 ppm
Styrene	700 ppm
Sulfur dioxide	100 ppm
1,1,2,2-Tetrachloroethane	100 ppm
Tetrachloroethylene	150 ppm
Tetrachloronaphthalene	Unknown
Tetraethyl lead (as Pb)	40 mg Pb/m <sup>3</sup>
Tetrahydrofuran	2,000 ppm
Tetramethyl lead (as Pb)	40 mg Pb/m <sup>3</sup>
Toluene	500 ppm
Toluene 2,4-diisocyanate	2.5 ppm
Trichloroethylene	1,000 ppm
Trichloronaphthalene	Unknown

Substance	IDLH Value
Uranium (insoluble compounds, as U)	10 mg U/m <sup>3</sup>
Uranium (soluble compounds, as U)	10 mg U/m <sup>3</sup>
Xylene (o, m, p isomers)	900 ppm
Zinc chloride fume	50 mg/m <sup>3</sup>
Zinc oxide	500 mg/m <sup>3</sup>

# APPENDIX X

## U.S. EPA NATIONAL AIR QUALITY INDEX

AQI Value	Air Quality	General Health Effects	Recommended Actions
0–50	Good	None	
51–100	Moderate	There may be moderate health concern for a very small number of individuals. People unusually sensitive to ozone may experience respiratory symptoms	When O <sub>3</sub> AQI values are in this range, unusually sensitive people should consider limiting prolonged outdoor exposure
101–150	Unhealthy for sensitive groups	Mild aggravation of symptoms in susceptible persons.	Active people with respiratory or heart disease should limit prolonged outdoor exertion.
151–200	Unhealthy	Aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Active children and adults with respiratory or heart disease should avoid extended outdoor activities; everyone else, especially children, should limit prolonged outdoor activity.
201–300	Very unhealthy	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Active children and adults with existing heart or lung disease should avoid outdoor activities and exertion. Everyone else, especially children, should limit outdoor exertion.
301–500	Hazardous	Significant aggravation of symptoms. Premature onset of certain diseases. Premature death may occur in ill or elderly people. Healthy people may experience a decrease in exercise tolerance.	Everyone should avoid all outdoor exertion and minimize physical outdoor activities. Elderly adults and persons with existing heart or lung disease should stay indoors.

Note: Used in air quality ratings in daily weather reports

# APPENDIX XI

## CHEMICALS ANALYZED AT SUPERFUND SITES

• Acetone	• Lead
• Aldrin/Dieldrin	• Mercury
• Arsenic	• Methylene Chloride
• Barium	• Naphthalene
• Benzene	• Nickel
• 2-Butanone	• Pentachlorophenol
• Cadmium	• Polychlorinated Biphenyls (PCBs)
• Carbon Tetrachloride	• Polycyclic Aromatic Hydrocarbons (PAHs)
• Chlordane	• Tetrachloroethylene
• Chloroform	• Toluene
• Chromium	• Trichloroethylene
• Cyanide	• Vinyl Chloride
• DDT, DDE, DDD	• Xylene: pending
• 1,1-Dichloroethene	• Zinc
• 1,2-Dichloroethane	



# APPENDIX XII

## U.S. NATIONAL PRIORITIES LIST (NPL OR SUPERFUND) SITES (FIGURES REPORTED AS OF NOVEMBER 29, 2010)

No.	Site Name	State/Location	Listing Date
1	Alabama Army Ammunition Plant	Alabama	1987
2	American Brass Inc.	Alabama	1999
3	Anniston Army Depot (Southeast Industrial Area)	Alabama	1989
4	Ciba-Geigy Corp. (Mcintosh Plant)	Alabama	1984
5	Interstate Lead Co. (Ilco)	Alabama	1986
6	Olin Corp. (Mcintosh Plant)	Alabama	1984
7	Perdido Groundwater Contamination	Alabama	1983
8	Redwing Carriers, Inc. (Saraland)	Alabama	1990
9	Stauffer Chemical Co. (Cold Creek Plant)	Alabama	1984
10	Stauffer Chemical Co. (Lemoyne Plant)	Alabama	1984
11	T. H. Agriculture & Nutrition Co. (Montgomery Plant)	Alabama	1990
12	Triana/Tennessee River	Alabama	1983
13	U.S. Army/NASA Redstone Arsenal	Alabama	1994
1	Adak Naval Air Station	Alaska	1994
2	Eielson Air Force Base	Alaska	1989
3	Elmendorf Air Force Base	Alaska	1990
4	Fort Richardson (U.S. Army)	Alaska	1994
5	Fort Wainwright	Alaska	1990
6	Salt Chuck Mine	Alaska	2010
1	Apache Powder Co.	Arizona	1990
2	Hassayampa Landfill	Arizona	1987
3	Indian Bend Wash Area	Arizona	1983
4	Iron King Mine–Humboldt Smelter	Arizona	2008
5	Motorola, Inc. (52nd Street Plant)	Arizona	1989
6	Phoenix-Goodyear Airport Area	Arizona	1983
7	Tucson International Airport Area	Arizona	1983

No.	Site Name	State/Location	Listing Date
8	Williams Air Force Base	Arizona	1989
9	Yuma Marine Corps Air Station	Arizona	1990
1	Arkwood, Inc.	Arkansas	1989
2	Midland Products	Arkansas	1986
3	Mid-South Wood Products	Arkansas	1983
4	Monroe Auto Equipment Co. (Paragould Pit)	Arkansas	1990
5	Mountain Pine Pressure Treating	Arkansas	1999
6	Ouachita Nevada Wood Treater	Arkansas	2000
7	Popile, Inc.	Arkansas	1992
8	Vertac, Inc.	Arkansas	1983
1	Advanced Micro Devices, Inc.	California	1986
2	Advanced Micro Devices, Inc. (Building 915)	California	1990
3	Aerojet General Corp.	California	1983
4	Alameda Naval Air Station	California	1999
5	Alark Hard Chrome	California	2000
6	AMCO Chemical	California	2003
7	Applied Materials	California	1987
8	Atlas Asbestos Mine	California	1984
9	Barstow Marine Corps Logistics Base	California	1989
10	Beckman Instruments (Porterville Plant)	California	1986
11	BF Goodrich	California	2009
12	Brown & Bryant, Inc. (Arvin Plant)	California	1989
13	Camp Pendleton Marine Corps Base	California	1989
14	Casmalia Resources	California	2001
15	Castle Air Force Base (six areas)	California	1987
16	Coast Wood Preserving	California	1983
17	Concord Naval Weapons Station	California	1994
18	Cooper Drum Co.	California	2001
19	Crazy Horse Sanitary Landfill	California	1990
20	CTS Printex, Inc.	California	1990
21	Del Amo	California	2002
22	Edwards Air Force Base	California	1990
23	El Toro Marine Corps Air Station	California	1990
24	Fairchild Semiconductor Corp. (Mountain View Plant)	California	1991

No.	Site Name	State/Location	Listing Date
25	Fairchild Semiconductor Corp. (South San Jose Plant)	California	1989
26	Fort Ord	California	1990
27	Fresno Municipal Sanitary Landfill	California	1989
28	Frontier Fertilizer	California	1994
29	George Air Force Base	California	1990
30	Halaco Engineering Co	California	2007
31	Hewlett-Packard (620–640 Page	California	1990
32	Industrial Waste Processing	California	1990
33	Intel Corp. (Mountain View Plant)	California	1986
34	Intel Corp. (Santa Clara III )	California	1986
35	Intel Magnetics	California	06/10/1986
36	Intersil Inc./Siemens Components	California	1990
37	Iron Mountain Mine	California	1983
38	J. H. Baxter & Co.	California	1989
39	Jasco Chemical Corp.	California	1989
40	Jet Propulsion Laboratory (NASA)	California	1992
41	Klau/Buena Vista Mine	California	2006
42	Koppers Co., Inc. (Oroville Plant)	California	1984
43	Lava Cap Mine	California	1999
44	Lawrence Livermore National Lab (Site 300) (U.S. DOE)	California	1990
45	Lawrence Livermore National Lab, Main Site (U.S. DOE)	California	1987
46	LEHR/Old Campus Landfill (U.S. DOE)	California	1994
47	Leviathan Mine	California	2000
48	Lorentz Barrel & Drum Co.	California	1989
49	March Air Force Base	California	1989
50	Mather Air Force Base (Ac&W Disposal Site)	California	1987
51	McClellan Air Force Base (Groundwater Contamination)	California	1987
52	McColl	California	1983
53	McCormick & Baxter Creosoting Co.	California	1992
54	MGM Brakes	California	1983
55	Modesto Groundwater Contamination	California	1989
56	Moffett Naval Air Station	California	1987
57	Monolithic Memories	California	1987
58	Montrose Chemical Corp.	California	1989
59	National Semiconductor Corp.	California	1987

No.	Site Name	State/Location	Listing Date
59	National Semiconductor Corp.	California	1987
60	Newmark Groundwater Contamination	California	1989
61	Norton Air Force Base (Landfill #2)	California	1987
62	Omega Chemical Corporation	California	1999
63	Operating Industries, Inc., Landfill	California	1986
64	Pacific Coast Pipe Lines	California	1989
65	Pemaco Maywood	California	1999
66	Purity Oil Sales, Inc.	California	1983
67	Raytheon Corp.	California	1986
68	Riverbank Army Ammunition Plant	California	1990
69	Sacramento Army Depot	California	1987
70	San Fernando Valley (Area 1)	California	1986
71	San Fernando Valley (Area 2)	California	1986
72	San Fernando Valley (Area 4)	California	1986
73	San Gabriel Valley (Area 1)	California	1984
74	San Gabriel Valley (Area 2)	California	1984
75	San Gabriel Valley (Area 3)	California	1984
76	San Gabriel Valley (Area 4)	California	1984
77	Selma Treating Co.	California	1983
78	Sharpe Army Depot	California	1987
79	Sola Optical USA, Inc.	California	1990
80	South Bay Asbestos Area	California	1986
81	Spectra-Physics, Inc.	California	1991
82	Stringfellow	California	1983
83	Sulphur Bank Mercury Mine	California	1990
84	Synertek, Inc. (Building 1)	California	1989
85	Teledyne Semiconductor	California	1987
86	Tracy Defense Depot (U.S. Army)	California	1990
87	Travis Air Force Base	California	1989
88	Treasure Island Naval Station—Hunters Point Annex	California	1989
89	TRW Microwave, Inc. (Building 825)	California	1990
90	United Heckathorn Co.	California	1990
91	Valley Wood Preserving, Inc.	California	1989
92	Waste Disposal, Inc.	California	1987
93	Watkins-Johnson Co. (Stewart Division Plant)	California	1990



No.	Site Name	State/Location	Listing Date
94	Westinghouse Electric Corp. (Sunnyvale Plant)	California	1986
1	Air Force Plant PJKS	Colorado	1989
2	Broderick Wood Products	Colorado	1984
3	California Gulch	Colorado	1983
4	Captain Jack Mill	Colorado	2003
5	Central City, Clear Creek	Colorado	1983
6	Chemical Sales Co.	Colorado	1990
7	Denver Radium Site	Colorado	1983
8	Eagle Mine	Colorado	1986
9	Lincoln Park	Colorado	1984
10	Lowry Landfill	Colorado	1984
11	Marshall Landfill	Colorado	1983
12	Rocky Flats Plant (U.S. DOE)	Colorado	1989
13	Rocky Mountain Arsenal (U.S. Army)	Colorado	1987
14	Standard Mine	Colorado	2005
15	Summitville Mine	Colorado	1994
16	Uravan Uranium Project (Union Carbide Corp.)	Colorado	1986
17	Vasquez Boulevard and I-70	Colorado	1999
1	Barkhamsted–New Hartford Landfill	Connecticut	1989
2	Beacon Heights Landfill	Connecticut	1983
3	Durham Meadows	Connecticut	1989
4	Gallup's Quarry	Connecticut	1989
5	Kellogg-Deering Well Field	Connecticut	1984
6	Laurel Park, Inc.	Connecticut	1983
7	Linemaster Switch Corp.	Connecticut	1990
8	New London Submarine Base	Connecticut	1990
9	Old Southington Landfill	Connecticut	1984
10	Precision Plating Corp.	Connecticut	1989
11	Raymark Industries, Inc.	Connecticut	1995
12	Scovill Industrial Landfill	Connecticut	2000
13	Solvents Recovery Service of New England	Connecticut	1983
14	Yaworski Waste Lagoon	Connecticut	1983
1	Army Creek Landfill	Delaware	1983

No.	Site Name	State/Location	Listing Date
2	Chem-Solv, Inc.	Delaware	1990
3	Coker's Sanitation Service Landfills	Delaware	1987
4	Delaware City PVC Plant	Delaware	1983
5	Delaware Sand & Gravel Landfill	Delaware	1983
6	Dover Air Force Base	Delaware	1989
7	Dover Gas Light Co.	Delaware	1989
8	E. I. Du Pont de Nemours & Co., Inc. (Newport Pigment Plant Landfill)	Delaware	1990
9	Halby Chemical Co.	Delaware	1986
10	Harvey & Knott Drum, Inc.	Delaware	1983
11	Koppers Co., Inc. (Newport Plant)	Delaware	1990
12	NCR Corp. (Millsboro Plant)	Delaware	1987
13	Standard Chlorine of Delaware, Inc.	Delaware	1987
14	Tybouts Corner Landfill	Delaware	1983
1	Washington Navy Yard	District of Columbia	1998
1	Agrico Chemical Co.	Florida	1989
2	Airco Plating Co.	Florida	1990
3	Alaric Area GW Plume	Florida	2000
4	American Creosote Works, Inc. (Pensacola Plant)	Florida	1983
5	Anodyne, Inc.	Florida	1990
6	B&B Chemical Co., Inc.	Florida	1990
7	Cabot/Koppers	Florida	1984
8	Chevron Chemical Co. (Ortho Division)	Florida	1994
9	City Industries, Inc.	Florida	1989
10	Coleman-Evans Wood Preserving Co.	Florida	1983
11	Escambia Wood—Pensacola	Florida	1994
12	Flash Cleaners	Florida	2008
13	Florida Petroleum Reprocessors	Florida	1998
14	Florida Steel Corp.	Florida	1983
15	General Dynamics Longwood	Florida	2010
16	Harris Corp. (Palm Bay Plant)	Florida	1987
17	Helena Chemical Co. (Tampa Plant)	Florida	1992
18	Hipps Road Landfill	Florida	1984
19	Hollingsworth Solderless Terminal	Florida	1983

No.	Site Name	State/Location	Listing Date
20	Homestead Air Force Base	Florida	1990
21	Jacksonville Naval Air Station	Florida	1989
22	J J Seifert Machine	Florida	2010
23	Landia Chemical Company	Florida	2000
24	Kerr-McGee Chemical Corp.—Jackson	Florida	2010
25	Madison County Sanitary Landfill	Florida	1990
26	Miami Drum Services	Florida	1983
27	MRI Corp (Tampa)	Florida	1986
28	Peak Oil Co./Bay Drum Co.	Florida	1986
29	Pensacola Naval Air Station	Florida	1989
30	Pepper Steel & Alloys, Inc.	Florida	1984
31	Petroleum Products Corp.	Florida	1987
32	Pickettville Road Landfill	Florida	1983
33	Piper Aircraft Corp./Vero Beach Water & Sewer Department	Florida	1990
34	Raleigh Street Dump	Florida	2009
35	Reeves Southeastern Galvanizing Corp.	Florida	1983
36	Sanford Dry Cleaners	Florida	2010
37	Sapp Battery Salvage	Florida	1983
38	Sherwood Medical Industries	Florida	1983
39	Solitron Microwave	Florida	1998
40	Southern Solvents, Inc.	Florida	2000
41	Stauffer Chemical Co (Tampa)	Florida	1996
42	Stauffer Chemical Co. (Tarpon Springs)	Florida	1994
43	Sydney Mine Sludge Ponds	Florida	1989
44	Taylor Road Landfill	Florida	1983
45	Tower Chemical Co.	Florida	1983
46	Trans Circuits, Inc.	Florida	2000
47	Tyndall Air Force Base	Florida	1997
48	United Metals, Inc.	Florida	2003
49	USN Air Station Cecil Field	Florida	1989
50	Whitehouse Oil Pits	Florida	1983
51	Whiting Field Naval Air Station	Florida	1994
52	Wingate Road Municipal Incinerator Dump	Florida	1989
53	Zellwood Groundwater Contamination	Florida	1983
1	Alternate Energy Resources	Georgia	2006

No.	Site Name	State/Location	Listing Date
2	Brunswick Wood Preserving	Georgia	1997
3	Camilla Wood Preserving Company	Georgia	1998
4	Diamond Shamrock Corp. Landfill	Georgia	1990
5	Firestone Tire & Rubber Co. (Albany Plant)	Georgia	1989
6	Hercules 009 Landfill	Georgia	1984
7	LCP Chemicals Georgia	Georgia	1996
8	Marine Corps Logistics Base	Georgia	1989
9	Marzone Inc./Chevron Chemical Co.	Georgia	1989
10	Mathis Brothers Landfill (South Marble Top Road)	Georgia	1989
11	Peach Orchard Road Pce Ground Water Plume	Georgia	2005
12	Robins Air Force Base (Landfill #4/Sludge Lagoon)	Georgia	1987
13	T.H. Agriculture & Nutrition Co. (Albany Plant)	Georgia	1989
14	Woolfolk Chemical Works, Inc.	Georgia	1990
1	Andersen Air Force Base	Guam	1992
2	Ordot Landfill	Guam	1983
1	Del Monte Corp. (Oahu Plantation)	Hawaii	1994
2	Naval Computer and Telecommunications Area Master Station Eastern Pacific	Hawaii	1994
3	Pearl Harbor Naval Complex	Hawaii	1992
1	Bunker Hill Mining & Metallurgical Complex	Idaho	1983
2	Eastern Michaud Flats Contamination	Idaho	1990
3	Idaho National Engineering Laboratory (U.S. DOE)	Idaho	1989
4	Kerr-McGee Chemical Corp. (Soda Springs Plant)	Idaho	1989
5	Monsanto Chemical Co. (Soda Springs Plant)	Idaho	1990
6	Mountain Home Air Force Base	Idaho	1990
1	A & F Material Reclaiming, Inc.	Illinois	1983
2	Acme Solvent Reclaiming, Inc. (Morristown Plant)	Illinois	1983
3	Adams County Quincy Landfills 2 & 3	Illinois	1990
4	Amoco Chemicals (Joliet Landfill)	Illinois	1990
5	ASARCO Taylor Springs	Illinois	2006
6	Beloit Corp.	Illinois	1990
7	Belvidere Municipal Landfill	Illinois	1983



No.	Site Name	State/Location	Listing Date
8	Byron Salvage Yard	Illinois	1983
9	Central Illinois Public Service Co.	Illinois	1990
10	Cross Brothers Pail Recycling (Pembroke)	Illinois	1983
11	Depue/New Jersey Zinc/Mobil Chemical Corp.	Illinois	1999
12	Dupage County Landfill/Blackwell Forest Preserve	Illinois	1990
13	Eagle Zinc Co. Div. of T. L. Diamond	Illinois	2007
14	Galesburg/Koppers Co.	Illinois	1983
15	H.O.D. Landfill	Illinois	1990
16	Hegeler Zinc	Illinois	2005
17	Indian Refinery—Texaco Lawrenceville	Illinois	2000
18	Interstate Pollution Control, Inc.	Illinois	1989
19	Jennison-Wright Corporation	Illinois	1996
20	Johns-Manville Corp.	Illinois	1983
21	Joliet Army Ammunition Plant (Load-Assembly-Packing Area)	Illinois	1989
22	Joliet Army Ammunition Plant (Manufacturing Area)	Illinois	1987
23	Kerr-McGee (Kress Creek/West Branch of Dupage River)	Illinois	1991
24	Kerr-McGee (Residential Areas)	Illinois	1990
25	Kerr-McGee (Sewage Treatment Plant)	Illinois	1990
26	Lake Calumet Cluster	Illinois	2010
27	Lasalle Electric Utilities	Illinois	1983
28	Lenz Oil Service, Inc.	Illinois	1989
29	Matthiessen and Hegeler Zinc Company	Illinois	2003
30	MIG/Dewane Landfill	Illinois	1990
31	NL Industries/Taracorp Lead Smelter	Illinois	1986
32	Ottawa Radiation Areas	Illinois	1992
33	Outboard Marine Corp.	Illinois	1983
34	Pagel's Pit	Illinois	1986
35	Parsons Casket Hardware Co.	Illinois	1987
36	Sangamo Electric Dump/Crab Orchard National Wildlife Refuge (U.S. DOI)	Illinois	1987
37	Savanna Army Depot Activity	Illinois	1989
38	Southeast Rockford Groundwater Contamination	Illinois	1989
39	Tri-County Landfill Co./Waste Management of Illinois, Inc.	Illinois	1989
40	Velsicol Chemical Corp. (Marshall Plant)	Illinois	1983
41	Wauconda Sand & Gravel	Illinois	1983
42	Woodstock Municipal Landfill	Illinois	1989
43	Yeoman Creek Landfill	Illinois	1989

No.	Site Name	State/Location	Listing Date
1	American Chemical Service, Inc.	Indiana	1984
2	Bennett Stone Quarry	Indiana	1984
3	Cam-Or, Inc.	Indiana	1998
4	Columbus Old Municipal Landfill #1	Indiana	1986
5	Conrail Rail Yard (Elkhart)	Indiana	1990
6	Continental Steel Corp.	Indiana	1989
7	Douglass Road/Uniroyal, Inc., Landfill	Indiana	1989
8	Elm Street Groundwater Contamination	Indiana	2007
9	Envirochem Corp.	Indiana	1983
10	Fisher-Calo	Indiana	1983
11	Fort Wayne Reduction Dump	Indiana	1986
12	Galen Myers Dump/Drum Salvage	Indiana	1989
13	Himco Dump	Indiana	1990
14	Jacobsville Neighborhood Soil Contamination	Indiana	2004
15	Lake Sandy Jo (M&M Landfill)	Indiana	1983
16	Lakeland Disposal Service, Inc.	Indiana	1989
17	Lemon Lane Landfill	Indiana	1983
18	Lusher Street Groundwater Contamination	Indiana	2008
19	Main Street Well Field	Indiana	1983
20	Marion (Bragg) Dump	Indiana	1983
21	MIDCO I	Indiana	1983
22	MIDCO II	Indiana	1986
23	Neal's Landfill (Bloomington)	Indiana	1983
24	Ninth Avenue Dump	Indiana	1983
25	Northside Sanitary Landfill, Inc.	Indiana	1984
26	Prestolite Battery Division	Indiana	1989
27	Reilly Tar & Chemical Corp. (Indianapolis Plant)	Indiana	1984
28	Seymour Recycling Corp.	Indiana	1983
29	Tippecanoe Sanitary Landfill, Inc.	Indiana	1990
30	U.S. Smelter and Lead Refinery, Inc.	Indiana	2009
31	Wayne Waste Oil	Indiana	1983
1	Des Moines TCE	Iowa	1983
2	Electro-Coatings, Inc.	Iowa	1989
3	Fairfield Coal Gasification Plant	Iowa	1990
4	Iowa Army Ammunition Plant	Iowa	1990

No.	Site Name	State/Location	Listing Date
5	Lawrence Todtz Farm	Iowa	1986
6	Mason City Coal Gasification Plant	Iowa	1994
7	Midwest Manufacturing/North Farm	Iowa	1986
8	Peoples Natural Gas Co.	Iowa	1990
9	Railroad Avenue Groundwater Contamination Site	Iowa	2002
10	Shaw Avenue Dump	Iowa	1987
11	Vogel Paint & Wax Co.	Iowa	1986
1	57th and North Broadway Streets Site	Kansas	1992
2	Ace Services	Kansas	1995
3	Chemical Commodities, Inc.	Kansas	1994
4	Cherokee County	Kansas	1983
5	Doepke Disposal (Holliday)	Kansas	1983
6	Fort Riley	Kansas	1990
7	Obee Road	Kansas	1987
8	Pester Refinery Co.	Kansas	1989
9	Plating, Inc.	Kansas	2008
10	Strother Field Industrial Park	Kansas	1986
11	Wright Ground Water Contamination	Kansas	1996
1	Airco	Kentucky	1984
2	B. F. Goodrich	Kentucky	1983
3	Brantley Landfill	Kentucky	1990
4	Caldwell Lace Leather Co., Inc.	Kentucky	1990
5	Distler Brickyard	Kentucky	1983
6	Distler Farm	Kentucky	1983
7	Fort Hartford Coal Co. Stone Quarry	Kentucky	1990
8	Green River Disposal, Inc.	Kentucky	1990
9	Maxey Flats Nuclear Disposal	Kentucky	1986
10	National Electric Coil Co./Cooper Industries	Kentucky	1992
11	National Southwire Aluminum Co.	Kentucky	1994
12	Paducah Gaseous Diffusion Plant (U.S. DOE)	Kentucky	1994
13	Smith's Farm	Kentucky	1986
14	Tri-City Disposal Co.	Kentucky	1989
1	Agriculture Street Landfill	Louisiana	1994

No.	Site Name	State/Location	Listing Date
2	American Creosote Works, Inc. (Winnfield Plant)	Louisiana	1992
3	Bayou Bonfouca	Louisiana	1983
4	Combustion, Inc.	Louisiana	1990
5	Louisiana Army Ammunition Plant	Louisiana	1989
6	Madisonville Creosote Works	Louisiana	1996
7	Marion Pressure Treating	Louisiana	2000
8	Petro-Processors of Louisiana, Inc.	Louisiana	1984
1	Brunswick Naval Air Station	Maine	1987
2	Callahan Mining Corp	Maine	2002
3	Eastern Surplus	Maine	1996
4	Eastland Woolen Mill	Maine	1999
5	Loring Air Force Base	Maine	1990
6	McKin Co.	Maine	1983
7	O'Connor Co.	Maine	1983
8	Portsmouth Naval Shipyard	Maine	1994
9	Saco Municipal Landfill	Maine	1990
10	Union Chemical Co., Inc.	Maine	1989
11	West Site/Hows Corners	Maine	1995
12	Winthrop Landfill	Maine	1983
1	Aberdeen Proving Ground (Edgewood Area)	Maryland	1990
2	Aberdeen Proving Ground (Michaelsville Landfill)	Maryland	1989
3	Andrews Air Force Base	Maryland	1999
4	Beltsville Agricultural Research Center (USDA)	Maryland	1994
5	Brandywine DRMO	Maryland	1999
6	Bush Valley Landfill	Maryland	1989
7	Central Chemical (Hagerstown)	Maryland	1997
8	Curtis Bay Coast Guard Yard	Maryland	2002
9	Fort George G. Meade	Maryland	1998
10	Indian Head Naval Surface Warfare Center	Maryland	1995
11	Kane & Lombard Street Drums	Maryland	1986
12	Limestone Road	Maryland	1983
13	Ordnance Products, Inc.	Maryland	1997
14	Patuxent River Naval Air Station	Maryland	1994
15	Sand, Gravel and Stone	Maryland	1983



No.	Site Name	State/Location	Listing Date
16	Spectron, Inc.	Maryland	1994
17	Woodlawn County Landfill	Maryland	1987
1	Atlas Tack Corp.	Massachusetts	1990
2	Baird & McGuire	Massachusetts	1983
3	Blackburn & Union Privileges	Massachusetts	1994
4	Cannon Engineering Corp. (CEC)	Massachusetts	1983
5	Charles-George Reclamation Trust Landfill	Massachusetts	1983
6	Fort Devens	Massachusetts	1998
7	Groveland Wells	Massachusetts	1983
8	Hanscom Field/Hanscom Air Force Base	Massachusetts	1994
9	Hatheway & Patterson	Massachusetts	2002
10	Haverhill Municipal Landfill	Massachusetts	1986
11	Hocomonco Pond	Massachusetts	1983
12	Industri-Plex	Massachusetts	1983
13	Iron Horse Park	Massachusetts	1984
14	Natick Laboratory Army Research, Development, and Engineering Center	Massachusetts	1994
15	Naval Weapons Industrial Reserve Plant	Massachusetts	1994
16	New Bedford Site	Massachusetts	1983
17	Norwood PCBs	Massachusetts	1986
18	Nuclear Metals, Inc.	Massachusetts	2001
19	Nyanza Chemical Waste Dump	Massachusetts	1983
20	Olin Chemical	Massachusetts	2006
21	Otis Air National Guard Base/Camp Edwards	Massachusetts	1998
22	PSC Resources	Massachusetts	1983
23	Re-Solve, Inc.	Massachusetts	1983
24	Rose Disposal Pit	Massachusetts	1986
25	Shpack Landfill	Massachusetts	1986
26	Silresim Chemical Corp.	Massachusetts	1983
27	South Weymouth Naval Air Station	Massachusetts	1994
28	Sullivan's Ledge	Massachusetts	1984
29	Sutton Brook Disposal Area	Massachusetts	2001
30	W. R. Grace & Co., Inc. (Acton Plant)	Massachusetts	1983
31	Wells G & H	Massachusetts	1983

No.	Site Name	State/Location	Listing Date
1	Adam's Plating	Michigan	1989
2	Aircraft Components (D & L Sales)	Michigan	1996
3	Albion-Sheridan Township Landfill	Michigan	1989
4	Allied Paper, Inc./Portage Creek/Kalamazoo River	Michigan	1990
5	American Anodco, Inc.	Michigan	1989
6	Auto Ion Chemicals, Inc.	Michigan	1983
7	Barrels, Inc.	Michigan	1989
8	Bendix Corp./Allied Automotive	Michigan	1990
9	Bofors Nobel, Inc.	Michigan	1989
10	Burrows Sanitation	Michigan	1984
11	Butterworth #2 Landfill	Michigan	1983
12	Cannelton Industries, Inc.	Michigan	1990
13	Chem Central	Michigan	1983
14	Clare Water Supply	Michigan	1984
15	Duell & Gardner Landfill	Michigan	1983
16	Electrovoice	Michigan	1984
17	Forest Waste Products	Michigan	1983
18	G&H Landfill	Michigan	1983
19	Grand Traverse Overall Supply Co.	Michigan	1983
20	Gratiot County Golf Course	Michigan	2010
21	Gratiot County Landfill	Michigan	1983
22	H. Brown Co., Inc.	Michigan	1986
23	Hedblum Industries	Michigan	1983
24	Hi-Mill Manufacturing Co.	Michigan	1990
25	Ionia City Landfill	Michigan	1983
26	J & L Landfill	Michigan	1989
27	K & L Avenue Landfill	Michigan	1983
28	Kaydon Corp.	Michigan	1990
29	Kentwood Landfill	Michigan	1983
30	Kysor Industrial Corp.	Michigan	1989
31	Liquid Disposal, Inc.	Michigan	1983
32	McGraw Edison Corp.	Michigan	1983
33	Metamora Landfill	Michigan	1984
34	Michigan Disposal Service (Cork Street Landfill)	Michigan	1990
35	Motor Wheel, Inc.	Michigan	1986

No.	Site Name	State/Location	Listing Date
36	Muskegon Chemical Co.	Michigan	1990
37	North Bronson Industrial Area	Michigan	1986
38	Northernair Plating	Michigan	1983
39	Organic Chemicals, Inc.	Michigan	1983
40	Ott/Story/Cordova Chemical Co.	Michigan	1983
41	Packaging Corp. of America	Michigan	1983
42	Parsons Chemical Works, Inc.	Michigan	1989
43	Peerless Plating Co.	Michigan	1990
44	Petoskey Municipal Well Field	Michigan	1983
45	Rasmussen's Dump	Michigan	1983
46	Rockwell International Corp. (Allegan Plant)	Michigan	1987
47	Rose Township Dump	Michigan	1983
48	Roto-Finish Co., Inc.	Michigan	1986
49	SCA Independent Landfill	Michigan	1983
50	Shiawassee River	Michigan	1983
51	South Macomb Disposal Authority (Landfill 9 and #9a)	Michigan	1986
52	Southwest Ottawa County Landfill	Michigan	1983
53	Sparta Landfill	Michigan	1983
54	Spartan Chemical Co.	Michigan	1983
55	Spiegelberg Landfill	Michigan	1983
56	Springfield Township Dump	Michigan	1983
57	State Disposal Landfill, Inc.	Michigan	1990
58	Sturgis Municipal Wells	Michigan	1984
59	Tar Lake	Michigan	1983
60	Ten Mile Drain	Michigan	2010
61	Thermo-Chem, Inc.	Michigan	1986
62	Torch Lake	Michigan	1986
63	U.S. Aviex	Michigan	1983
64	Velsicol Chemical Corp. (Michigan)	Michigan	1983
65	Verona Well Field	Michigan	1983
66	Wash King Laundry	Michigan	1983
67	Waste Management of Michigan (Holland Lagoons)	Michigan	1986
1	Arrowhead Refinery Co.	Minnesota	1984
2	Baytown Township Groundwater Plume	Minnesota	1994
3	Burlington Northern (Brainerd/Baxter Plant)	Minnesota	1983

No.	Site Name	State/Location	Listing Date
4	FMC Corp. (Fridley Plant)	Minnesota	1983
5	Freeway Sanitary Landfill	Minnesota	1986
6	Fridley Commons Park Well Field	Minnesota	1999
7	General Mills/Henkel Corp.	Minnesota	1984
8	Joslyn Manufacturing & Supply	Minnesota	1984
9	Koppers Coke	Minnesota	1983
10	Kurt Manufacturing Co.	Minnesota	1986
11	Lehillier/Mankato	Minnesota	1983
12	Long Prairie Groundwater Contamination	Minnesota	1986
13	MacGillis & Gibbs Co./Bell Lumber & Pole Co.	Minnesota	1984
14	Naval Industrial Reserve Ordnance Plant	Minnesota	1989
15	New Brighton/Arden Hills/TCAAP (U.S. Army)	Minnesota	1983
16	Nutting Truck & Caster Co.	Minnesota	1984
17	Oakdale Dump	Minnesota	1983
18	Perham Arsenic Site	Minnesota	1984
19	Reilly Tar & Chemical Corp. (St. Louis Park Plant)	Minnesota	1983
20	Ritari Post & Pole	Minnesota	1987
21	South Andover Site	Minnesota	1983
22	South Minneapolis Neighborhood Soil Contamination Site	Minnesota	2007
23	St. Louis River Site	Minnesota	1984
24	St. Regis Paper Co.	Minnesota	1984
25	Waite Park Wells	Minnesota	1986
1	American Creosote Works Inc.	Mississippi	2001
2	Davis Timber Company	Mississippi	2000
3	Picayune Wood Treating Site	Mississippi	2004
4	Sonford Products	Mississippi	2007
1	Annapolis Lead Mine	Missouri	2004
2	Armour Road	Missouri	1999
3	Bee Cee Manufacturing Co.	Missouri	1986
4	Big River Mine Tailings/St. Joe Minerals Corp.	Missouri	1992
5	Conservation Chemical Co.	Missouri	1989
6	Ellisville Site	Missouri	1983
7	Fulbright Landfill	Missouri	1983
8	Lake City Army Ammunition Plant (Northwest Lagoon)	Missouri	1987



No.	Site Name	State/Location	Listing Date
9	Lee Chemical	Missouri	1986
10	Madison Mine (Anschutz Mining Corp)	Missouri	2003
11	Minker/Stout/Romaine Creek	Missouri	1983
12	Missouri Electric Works	Missouri	1990
13	Newton County Mine Tailings	Missouri	2003
14	Newton County Wells	Missouri	2000
15	Oak Grove Village Well	Missouri	2002
16	Oronogo-Duenweg Mining Belt	Missouri	1990
17	Pools Prairie	Missouri	1999
18	Quality Plating	Missouri	1986
19	Riverfront	Missouri	2000
20	Solid State Circuits, Inc.	Missouri	1986
21	Southwest Jefferson County Mining	Missouri	2009
22	St. Louis Airport/Hazelwood Interim Storage/Futura Coatings Co.	Missouri	1989
23	Syntex Facility	Missouri	1983
24	Valley Park TCE	Missouri	1986
25	Vienna Wells	Missouri	2010
26	Washington County Lead District—Old Mines	Missouri	2008
27	Washington County Lead District—Potosi	Missouri	2008
28	Washington County Lead District—Richwoods	Missouri	2008
29	Weldon Spring Former Army Ordnance Works	Missouri	1990
30	Weldon Spring Quarry/Plant/Pits (U.S. DOE/Army)	Missouri	1987
31	Westlake Landfill	Missouri	1990
1	Anaconda Co. Smelter	Montana	1983
2	Barker Hughesville Mining District	Montana	2001
3	Basin Mining Area	Montana	1999
4	Carpenter Snow Creek Mining District	Montana	2001
5	East Helena Site	Montana	1984
6	Flat Creek IMM	Montana	2009
7	Idaho Pole Co.	Montana	1986
8	Libby Asbestos Site	Montana	2002
9	Libby Groundwater Contamination	Montana	1983
10	Lockwood Solvent Groundwater Plume	Montana	2000
11	Milltown Reservoir Sediments	Montana	1983
12	Montana Pole and Treating	Montana	1987

No.	Site Name	State/Location	Listing Date
13	Mouat Industries	Montana	1986
14	Silver Bow Creek/Butte Area	Montana	1983
15	Upper Tenmile Creek Mining Area	Montana	1999
1	10th Street Site	Nebraska	1990
2	Bruno Co-Op Association/Associated Properties	Nebraska	1996
3	Cleburn Street Well	Nebraska	1992
4	Cornhusker Army Ammunition Plant	Nebraska	1987
5	Garvey Elevator	Nebraska	2005
6	Hastings Groundwater Contamination	Nebraska	1986
7	Lindsay Manufacturing Co.	Nebraska	1989
8	Nebraska Ordnance Plant (former)	Nebraska	1990
9	Ogallala Groundwater Contamination	Nebraska	1994
10	Omaha Lead	Nebraska	2003
11	Parkview Well	Nebraska	2006
12	Sherwood Medical Co.	Nebraska	1992
13	West Highway 6 and Highway 281	Nebraska	2006
1	Carson River Mercury Site	Nevada	1990
1	Auburn Road Landfill	New Hampshire	1983
2	Beede Waste OilNew	New Hampshire	1996
3	Chlor-Alkali Facility (former)	New Hampshire	2005
4	Coakley Landfill	New Hampshire	1986
5	Dover Municipal Landfill	New Hampshire	1983
6	Fletcher's Paint Works & Storage	New Hampshire	1989
7	Kearsarge Metallurgical Corp.	New Hampshire	1984
8	Keefe Environmental Services (KES)	New Hampshire	1983
9	Mottolo Pig Farm	New Hampshire	1987
10	New Hampshire Plating Co.	New Hampshire	1992
11	Ottati & Goss/Kingston Steel Drum	New Hampshire	1983
12	Pease Air Force Base	New Hampshire	1990
13	Savage Municipal Water Supply	New Hampshire	1984
14	Somersworth Sanitary Landfill	New Hampshire	1983
15	South Municipal Water Supply Well	New Hampshire	1984
16	Sylvester	New Hampshire	1983

No.	Site Name	State/Location	Listing Date
17	Tibbetts Road	New Hampshire	1986
18	Tinkham Garage	New Hampshire	1983
19	Town Garage/Radio Beacon	New Hampshire	1989
20	Troy Mills Landfill	New Hampshire	2003
1	American Cyanamid Co.	New Jersey	1983
2	A. O. Polymer	New Jersey	1983
3	Atlantic Resources	New Jersey	2002
4	Bog Creek Farm	New Jersey	1983
5	Brick Township Landfill	New Jersey	1983
6	Bridgeport Rental & Oil Services	New Jersey	1983
7	Brook Industrial Park	New Jersey	1989
8	Burnt Fly Bog	New Jersey	1983
9	Caldwell Trucking Co.	New Jersey	1983
10	Chemical Control	New Jersey	1983
11	Chemical Insecticide Corp.	New Jersey	1990
12	Chemical Leaman Tank Lines, Inc.	New Jersey	1984
13	Chemsol, Inc.	New Jersey	1983
14	Ciba-Geigy Corp.	New Jersey	1983
15	Cinnamison Township (Block 702) Groundwater Contamination	New Jersey	1986
16	Combe Fill South Landfill	New Jersey	1983
17	Cornell Dubilier Electronics Inc.	New Jersey	1998
18	Cosden Chemical Coatings Corp.	New Jersey	1987
19	CPS/Madison Industries	New Jersey	1983
20	Crown Vantage Landfill	New Jersey	2005
21	Curcio Scrap Metal, Inc.	New Jersey	1983
22	Dayco Corp./L. E Carpenter Co.	New Jersey	1987
23	De Rewal Chemical Co.	New Jersey	1984
24	Diamond Alkali Co.	New Jersey	1984
25	Diamond Head Oil Refinery Div.	New Jersey	2002
26	D'Imperio Property	New Jersey	1983
27	Dover Municipal Well 4	New Jersey	1983
28	Ellis Property	New Jersey	1983
29	Emmell's Septic Landfill	New Jersey	1999
30	Evor Phillips Leasing	New Jersey	1983
31	Ewan Property	New Jersey	1984

No.	Site Name	State/Location	Listing Date
32	Fair Lawn Well Field	New Jersey	1983
33	Federal Aviation Administration Technical Center (U.S. DOT)	New Jersey	1990
34	Federal Creosote	New Jersey	1999
35	Fort Dix (Landfill Site)	New Jersey	1987
36	Franklin Burn	New Jersey	1996
37	Fried Industries	New Jersey	1986
38	Garden State Cleaners Co.	New Jersey	1989
39	GEMS Landfill	New Jersey	1983
40	Global Sanitary Landfill	New Jersey	1989
41	Goose Farm	New Jersey	1983
42	Helen Kramer Landfill	New Jersey	1983
43	Hercules, Inc. (Gibbstown Plant)	New Jersey	1983
44	Higgins Disposal	New Jersey	1990
45	Higgins Farm	New Jersey	1989
46	Horseshoe Road	New Jersey	1995
47	Iceland Coin Laundry Area Groundwater Plume	New Jersey	1999
48	Imperial Oil Co., Inc./Champion Chemicals	New Jersey	1983
49	JIS Landfill	New Jersey	1983
50	Kauffman & Minter, Inc.	New Jersey	1989
51	Kin-Buc Landfill	New Jersey	1983
52	King of Prussia	New Jersey	1983
53	Landfill & Development Co.	New Jersey	1984
54	Lang Property	New Jersey	1983
55	LCP Chemicals, Inc.	New Jersey	1998
56	Lightman Drum Company	New Jersey	1999
57	Lipari Landfill	New Jersey	1983
58	Lone Pine Landfill	New Jersey	1983
59	Martin Aaron, Inc.	New Jersey	1999
60	Matteo & Sons Inc.	New Jersey	2006
61	Maywood Chemical Co.	New Jersey	1983
62	McGuire Air Force Base #1	New Jersey	1999
63	Metaltec/Aerosystems	New Jersey	1983
64	Middlesex Sampling Plant (U.S. DOE)	New Jersey	1999
65	Monitor Devices, Inc./Intercircuits, Inc.	New Jersey	1986
66	Montgomery Township Housing Development	New Jersey	1983
67	Myers Property	New Jersey	1983



No.	Site Name	State/Location	Listing Date
68	Nascolite Corp.	New Jersey	1984
69	Naval Air Engineering Center	New Jersey	1987
70	Naval Weapons Station Earle (Site A)	New Jersey	1990
71	NL Industries	New Jersey	1983
72	Picatinny Arsenal (U.S. Army)	New Jersey	1990
73	PJP Landfill	New Jersey	1983
74	Pohatcong Valley Groundwater Contamination	New Jersey	1989
75	Price Landfill	New Jersey	1983
76	Puchack Well Field	New Jersey	1998
77	Quanta Resources	New Jersey	2002
78	Radiation Technology, Inc.	New Jersey	1984
79	Raritan Bay Slag	New Jersey	2009
80	Reich Farms	New Jersey	1983
81	Ringwood Mines/Landfill	New Jersey	1983
82	Rockaway Borough Well Field	New Jersey	1983
83	Rockaway Township Wells	New Jersey	1983
84	Rocky Hill Municipal Well	New Jersey	1983
85	Roebbing Steel Co.	New Jersey	1983
86	Rolling Knolls Landfill	New Jersey	2003
87	Sayreville Landfill	New Jersey	1983
88	Scientific Chemical Processing	New Jersey	1983
89	Sharkey Landfill	New Jersey	1983
90	Sherwin-Williams/Hilliards Creek	New Jersey	2009
91	Shieldalloy Corp.	New Jersey	1984
92	South Jersey Clothing Co.	New Jersey	1989
93	Standard Chlorine Chemical Co., Inc.	New Jersey	2007
94	Swope Oil & Chemical Co.	New Jersey	1983
95	Syncon Resins	New Jersey	1983
96	U.S. Radium Corp.	New Jersey	1983
97	United States Avenue Burn	New Jersey	1999
98	Universal Oil Products (Chemical Division)	New Jersey	1983
99	Ventron/Velsicol	New Jersey	1984
100	Vineland Chemical Co., Inc.	New Jersey	1984
101	W. R. Grace & Co., Inc./Wayne Interim Storage Site (U.S. DOE)	New Jersey	1984
102	Waldick Aerospace Devices, Inc.	New Jersey	1986
103	Welsbach & General Gas Mantle (Camden Radiation)	New Jersey	1996

No.	Site Name	State/Location	Listing Date
104	White Chemical Corp.	New Jersey	1991
105	White Swan Laundry and Cleaner, Inc.	New Jersey	2004
106	Williams Property	New Jersey	1983
107	Woodbrook Road Dump	New Jersey	2003
108	Woodland Route 532 Dump	New Jersey	1984
109	Woodland Route 72 Dump	New Jersey	1984
110	Zschiegner Refining	New Jersey	1998
1	AT&SF (Albuquerque)	New Mexico	1994
2	Cimarron Mining Corp.	New Mexico	1989
3	Eagle Picher Carefree Batteries	New Mexico	2007
4	Fruit Avenue Plume	New Mexico	1999
5	Grants Chlorinated Solvents	New Mexico	2004
6	Griggs & Walnut Groundwater Plume	New Mexico	2001
7	Homestake Mining Co.	New Mexico	1983
8	Lee Acres Landfill (U.S. DOI)	New Mexico	1990
9	McGaffey and Main Groundwater Plume	New Mexico	2002
10	North Railroad Avenue Plume	New Mexico	1999
11	Prewitt Abandoned Refinery	New Mexico	1990
12	South Valley	New Mexico	1983
13	United Nuclear Corp.	New Mexico	1983
1	American Thermostat Co.	New York	1983
2	Applied Environmental Services	New York	1986
3	Black River PCBs	New York	2010
4	Brewster Well Field	New York	1983
5	Brookhaven National Laboratory (U.S. DOE)	New York	1989
6	Byron Barrel & Drum	New York	1986
7	Carroll & Dubies Sewage Disposal	New York	1990
8	Cayuga Groundwater Contamination Site	New York	2002
9	Circuitron Corp.	New York	1989
10	Claremont Polychemical	New York	1986
11	Colesville Municipal Landfill	New York	1986
12	Computer Circuits	New York	1999
13	Consolidated Iron and Metal	New York	2001
14	Cortese Landfill	New York	1986

No.	Site Name	State/Location	Listing Date
15	Crown Cleaners of Watertown, Inc.	New York	2002
16	Diaz Chemical Corp.	New York	2004
17	Ellenville Scrap Iron and Metal	New York	2002
18	Endicott Village Well Field	New York	1986
19	Facet Enterprises, Inc.	New York	1983
20	FMC C/O Diaz Chemical C/O FMC	New York	2004
21	FMC Corp. (Dublin Road Landfill)	New York	1986
22	Forest Glen Mobile Home Subdivision	New York	1989
23	Fulton Avenue	New York	1998
24	Fulton Terminals	New York	1983
25	GCL Tie and Treating Inc.	New York	1994
26	GE Moreau	New York	1983
27	General Motors (Central Foundry Division)	New York	1984
28	Genzale Plating Co.	New York	1987
29	Goldisc Recordings, Inc.	New York	1986
30	Gowanus Canal	New York	2010
31	Griffiss Air Force Base (11 Areas)	New York	1987
32	Haviland Complex	New York	1986
33	Hertel Landfill	New York	1986
34	Hiteman Leather	New York	1999
35	Hooker (Hyde Park)	New York	1983
36	Hooker (S Area)	New York	1983
37	Hooker Chemical & Plastics Corp./Ruco Polymer Corp.	New York	1986
38	Hopewell Precision	New York	2005
39	Hudson River PCBs	New York	1984
40	Islip Municipal Sanitary Landfill	New York	1989
41	Jackson Steel	New York	2000
42	Johnstown City Landfill	New York	1986
43	Jones Chemicals, Inc.	New York	1990
44	Kentucky Avenue Well Field	New York	1983
45	Lawrence Aviation Industries, Inc.	New York	2000
46	Lehigh Valley Railroad	New York	1999
47	Li Tungsten Corp.	New York	1992
48	Liberty Industrial Finishing	New York	1986
49	Little Valley	New York	1996
50	Ludlow Sand & Gravel	New York	1983

No.	Site Name	State/Location	Listing Date
51	MacKenzie Chemical Works	New York	2001
52	Malta Rocket Fuel Area	New York	1987
53	Mattiace Petrochemical Co., Inc.	New York	1989
54	Mercury Refining, Inc.	New York	1983
55	Mohonk Road Industrial Plant	New York	1999
56	Nepera Chemical Co., Inc.	New York	1986
57	Newton Creek	New York	2010
58	Niagara Mohawk Power Corp. (Saratoga Springs Plant)	New York	1990
59	Old Bethpage Landfill	New York	1983
60	Old Roosevelt Field Contaminated Groundwater Area	New York	2000
61	Olean Well Field	New York	1983
62	Onondaga Lake	New York	1994
63	Pasley Solvents & Chemicals, Inc.	New York	1986
64	Peninsula Boulevard Groundwater Plume	New York	2004
65	Peter Cooper	New York	1998
66	Plattsburgh Air Force Base	New York	1989
67	Pollution Abatement Services	New York	1983
68	Port Washington Landfill	New York	1983
69	Preferred Plating Corp.	New York	1986
70	Ramapo Landfill	New York	1983
71	Richardson Hill Road Landfill/Pond	New York	1987
72	Robintech, Inc./National Pipe Co.	New York	1986
73	Rosen Brothers Scrap Yard/Dump	New York	1989
74	Rowe Industries Groundwater Contamination	New York	1987
75	Sarney Farm	New York	1986
76	Sealand Restoration, Inc.	New York	1990
77	Seneca Army Depot	New York	1990
78	Shenandoah Road Groundwater Contamination	New York	2001
79	Sidney Landfill	New York	1989
80	Sinclair Refinery	New York	1983
81	Smithtown Groundwater Contamination	New York	1999
82	Solvent Savers	New York	1983
83	Stanton Cleaners Area Groundwater Contamination	New York	1999
84	Tri-Cities Barrel Co., Inc.	New York	1989
85	Vestal Water Supply Well 1-1	New York	1983
86	Volney Municipal Landfill	New York	1986



No.	Site Name	State/Location	Listing Date
87	York Oil Co.	New York	1983
1	ABC One Hour Cleaners	North Carolina	1989
2	Aberdeen Pesticide Dumps	North Carolina	1989
3	Barber Orchard	North Carolina	2001
4	Benfield Industries, Inc.	North Carolina	1989
5	Blue Ridge Plating Company	North Carolina	2005
6	Bypass 601 Groundwater Contamination	North Carolina	1986
7	Camp Lejeune Military Res. (U.S. Navy)	North Carolina	1989
8	Cape Fear Wood Preserving	North Carolina	1987
9	Carolina Transformer Co.	North Carolina	1987
10	Celanese Corp. (Shelby Fiber Operations)	North Carolina	1986
11	Charles Macon Lagoon and Drum Storage	North Carolina	1987
12	Chemtronics, Inc.	North Carolina	1983
13	Cherry Point Marine Corps Air Station	North Carolina	1994
14	Davis Park Road TCE	North Carolina	1999
15	FCX, Inc. (Statesville Plant)	North Carolina	1990
16	FCX, Inc. (Washington Plant)	North Carolina	1989
17	Geigy Chemical Corp. (Aberdeen Plant)	North Carolina	1989
18	General Electric Co./Shepherd Farm	North Carolina	1994
19	GMH Electronics	North Carolina	2009
20	Jadco-Hughes Facility	North Carolina	1986
21	JFD Electronics/Channel Master	North Carolina	1989
22	Kerr McGee Chemical Corp	North Carolina	2010
23	Koppers Co., Inc. (Morrisville Plant)	North Carolina	1989
24	Martin-Marietta, Sodyeco, Inc.	North Carolina	1983
25	National Starch & Chemical Corp.	North Carolina	1989
26	New Hanover County Airport Burn Pit	North Carolina	1989
27	North Belmont PCE	North Carolina	1999
28	North Carolina State University (Lot 86, Farm Unit #1)	North Carolina	1986
29	Ore Knob Mine	North Carolina	2009
30	Potter's Septic Tank Service Pits	North Carolina	1989
31	Ram Leather Care Site	North Carolina	2003
32	Reasor Chemical Company	North Carolina	2002
33	Sigmon's Septic Tank Service	North Carolina	2005
34	Ward Transformer	North Carolina	2003

No.	Site Name	State/Location	Listing Date
1	Allied Chemical & Ironton Coke	Ohio	1983
2	Behr Dayton Thermal VOC Phone	Ohio	2009
3	Big D Campground	Ohio	1983
4	Buckeye Reclamation	Ohio	1983
5	Chem-Dyne	Ohio	1983
6	Copley Square Plaza	Ohio	2005
7	E. H. Schilling Landfill	Ohio	1983
8	East Troy Contaminated Aquifer	Ohio	2008
9	Feed Materials Production Center (U.S. DOE)	Ohio	1989
10	Fields Brook	Ohio	1983
11	Fultz Landfill	Ohio	1983
12	Industrial Excess Landfill	Ohio	1986
13	Lammers Barrel Factory	Ohio	2003
14	Little Scioto River	Ohio	2009
15	Miami County Incinerator	Ohio	1984
16	Mound Plant (U.S. DOE)	Ohio	1989
17	Nease Chemical	Ohio	1983
18	New Carlisle Landfill	Ohio	2009
19	New Lyme Landfill	Ohio	1983
20	North Sanitary Landfill	Ohio	1994
21	Old Mill	Ohio	1983
22	Ormet Corp.	Ohio	1987
23	Powell Road Landfill	Ohio	1984
24	Pristine, Inc.	Ohio	1983
25	Reilly Tar & Chemical Corp. (Dover Plant)	Ohio	1990
26	Sanitary Landfill Co. (Industrial Waste Disposal Co., Inc.)	Ohio	1986
27	Skinner Landfill	Ohio	1983
28	South Point Plant	Ohio	1984
29	Summit National	Ohio	1983
30	TRW, Inc. (Minerva Plant)	Ohio	1989
31	United Scrap Lead Co., Inc.	Ohio	1984
32	Van Dale Junkyard	Ohio	1986
33	Wright-Patterson Air Force Base	Ohio	1989
34	Zanesville Well Field	Ohio	1983
1	Hardage/Criner	Oklahoma	1983

No.	Site Name	State/Location	Listing Date
2	Hudson Refinery	Oklahoma	1999
3	Imperial Refining Company	Oklahoma	2000
4	Mosley Road Sanitary Landfill	Oklahoma	1990
5	Oklahoma Refining Co.	Oklahoma	1990
6	Tar Creek (Ottawa County)	Oklahoma	1983
7	Tinker Air Force Base (Soldier Creek/Building 3001)	Oklahoma	1987
8	Tulsa Fuel and Manufacturing	Oklahoma	1999
1	Black Butte Mine	Oregon	2010
2	Formosa Mine	Oregon	2007
3	Fremont National Forest/White King and Lucky Lass Uranium Mines (USDA)	Oregon	1995
4	Harbor Oil, Inc.	Oregon	2003
5	McCormick & Baxter Creosoting Co. (Portland Plant)	Oregon	1994
6	Northwest Pipe & Casing/Hall Process Company	Oregon	1992
7	Portland Harbor	Oregon	2000
8	Reynolds Metals Company	Oregon	1994
9	Taylor Lumber and Treating	Oregon	2001
10	Teledyne Wah Chang	Oregon	1983
11	Umatilla Army Depot (Lagoons)	Oregon	1987
12	Union Pacific Railroad Co. Tie-Treating Plant	Oregon	1990
13	United Chrome Products, Inc.	Oregon	1984
1	A. I. W. Frank/Mid-County Mustang	Pennsylvania	1989
2	Avco Lycoming (Williamsport Division)	Pennsylvania	1990
3	Bally Groundwater Contamination	Pennsylvania	1987
4	Bell Landfill	Pennsylvania	1989
5	Bendix Flight Systems Division	Pennsylvania	1987
6	Berks Sand Pit	Pennsylvania	1984
7	Blosenski Landfill	Pennsylvania	1983
8	Boarhead Farms	Pennsylvania	1989
9	BoRit Asbestos	Pennsylvania	2009
10	Breslube-Penn, Inc.	Pennsylvania	1996
11	Brown's Battery Breaking	Pennsylvania	1986
12	Butler Mine Tunnel	Pennsylvania	1987
13	Butz Landfill	Pennsylvania	1989
14	C & D Recycling	Pennsylvania	1987

No.	Site Name	State/Location	Listing Date
15	Centre County Kepone	Pennsylvania	1983
16	Chem-Fab	Pennsylvania	2008
17	Commodore Semiconductor Group	Pennsylvania	1989
18	Craig Farm Drum	Pennsylvania	1983
19	Crater Resources, Inc./Keystone Coke Co./Alan Wood Steel Co.	Pennsylvania	1992
20	Crossley Farm	Pennsylvania	1992
21	Croydon TCE	Pennsylvania	1986
22	Cryoshem, Inc.	Pennsylvania	1989
23	Delta Quarries & Disposal, Inc./Stotler Landfill	Pennsylvania	1989
24	Dorney Road Landfill	Pennsylvania	1984
25	Douglassville Disposal	Pennsylvania	1983
26	Drake Chemical	Pennsylvania	1983
27	Dublin TCE Site	Pennsylvania	1990
28	East Mount Zion	Pennsylvania	1984
29	Eastern Diversified Metals	Pennsylvania	1989
30	Elizabethtown Landfill	Pennsylvania	1989
31	Fischer & Porter Co.	Pennsylvania	1983
32	Foote Mineral Co.	Pennsylvania	1992
33	Franklin Slag Pile (MDC)	Pennsylvania	2002
34	Havertown PCP	Pennsylvania	1983
35	Heleva Landfill	Pennsylvania	1983
36	Hellertown Manufacturing Co.	Pennsylvania	1989
37	Henderson Road	Pennsylvania	1984
38	Hunterstown Road	Pennsylvania	1986
39	Industrial Lane	Pennsylvania	1984
40	Jacks Creek/Sitkin Smelting & Refining, Inc.	Pennsylvania	1989
41	Jackson Ceramix Inc	Pennsylvania	2005
42	Keystone Sanitation Landfill	Pennsylvania	1987
43	Kimberton	Pennsylvania	1983
44	Letterkenny Army Depot (PDO Area)	Pennsylvania	1989
45	Letterkenny Army Depot (SE Area)	Pennsylvania	1987
46	Lindane Dump	Pennsylvania	1983
47	Lord-Shope Landfill	Pennsylvania	1983
48	Lower Darby Creek Area	Pennsylvania	2001
49	Malvern TCE	Pennsylvania	1983
50	Metal Banks	Pennsylvania	1983



No.	Site Name	State/Location	Listing Date
51	Mill Creek Dump	Pennsylvania	1984
52	Modern Sanitation Landfill	Pennsylvania	1986
53	Moyers Landfill	Pennsylvania	1983
54	MW Manufacturing	Pennsylvania	1986
55	Naval Air Development Center (8 Waste Areas)	Pennsylvania	1989
56	Navy Ships Parts Control Center	Pennsylvania	1994
57	North Penn—Area 1	Pennsylvania	1989
58	North Penn—Area 12	Pennsylvania	1990
59	North Penn—Area 2	Pennsylvania	1989
60	North Penn—Area 5	Pennsylvania	1989
61	North Penn—Area 6	Pennsylvania	1989
62	North Penn—Area 7	Pennsylvania	1989
63	Novak Sanitary Landfill	Pennsylvania	1989
64	Occidental Chemical Corp./Firestone Tire & Rubber Co.	Pennsylvania	1989
65	Ohio River Park	Pennsylvania	1990
66	Old City of York Landfill	Pennsylvania	1983
67	Old Wilmington Road Groundwater Contamination	Pennsylvania	2000
68	Osborne Landfill	Pennsylvania	1983
69	Palmerton Zinc Pile	Pennsylvania	1983
70	Paoli Rail Yard	Pennsylvania	1990
71	Price Battery	Pennsylvania	2005
72	Raymark	Pennsylvania	1989
73	Recticon/Allied Steel Corp.	Pennsylvania	1989
74	Revere Chemical Co.	Pennsylvania	1987
75	Rodale Manufacturing Co., Inc.	Pennsylvania	1992
76	Ryeland Road Arsenic Site	Pennsylvania	2004
77	Saegertown Industrial Area	Pennsylvania	1990
78	Safety Light Corporation	Pennsylvania	2005
79	Sharon Steel Corp (Farrell Works Disposal Area)	Pennsylvania	1998
80	Shriver's Corner	Pennsylvania	1986
81	Stanley Kessler	Pennsylvania	1983
82	Strasburg Landfill	Pennsylvania	1989
83	Tobyhanna Army Depot	Pennsylvania	1990
84	Tonolli Corp.	Pennsylvania	1989
85	Tyson's Dump	Pennsylvania	1984
86	UGI Columbia Gas Plant	Pennsylvania	1994

No.	Site Name	State/Location	Listing Date
87	Valmont TCE Site (Former Valmont Industrial Park)	Pennsylvania	2001
88	Walsh Landfill	Pennsylvania	1984
89	Watson Johnson Landfill	Pennsylvania	2001
90	Westinghouse Electric Corp. (Sharon Plant)	Pennsylvania	1990
91	Westinghouse Elevator Co. Plant	Pennsylvania	1986
92	Whitmoyer Laboratories	Pennsylvania	1986
93	William Dick Lagoons	Pennsylvania	1987
94	Willow Grove Naval Air and Air Reserve Station	Pennsylvania	1995
1	Atlantic Fleet Weapons Training Area—Vieques	Puerto Rico	2005
2	Barceloneta Landfill	Puerto Rico	1983
3	Cidra Groundwater Contamination	Puerto Rico	2004
4	Fibers Public Supply Wells	Puerto Rico	1984
5	Juncos Landfill	Puerto Rico	1983
6	Maunabo Urbano Public Wells	Puerto Rico	2006
7	Papelera Puertorriquena, Inc.	Puerto Rico	2009
8	Pesticide Warehouse I	Puerto Rico	2006
9	Pesticide Warehouse III	Puerto Rico	2003
10	San German Groundwater Contamination	Puerto Rico	2008
11	Scorpio Recycling, Inc.	Puerto Rico	2000
12	Upjohn Facility	Puerto Rico	1984
13	Vega Alta Public Supply Wells	Puerto Rico	1984
14	Vega Baja Solid Waste Disposal	Puerto Rico	1999
1	Central Landfill	Rhode Island	1986
2	Centredale Manor Restoration Project	Rhode Island	2000
3	Davis Liquid Waste	Rhode Island	1983
4	Davisville Naval Construction Battalion Center	Rhode Island	1989
5	Landfill & Resource Recovery, Inc. (L&RR)	Rhode Island	1983
6	Newport Naval Education & Training Center	Rhode Island	1989
7	Peterson/Puritan, Inc.	Rhode Island	1983
8	Picillo Farm	Rhode Island	1983
9	Rose Hill Regional Landfill	Rhode Island	1989
10	Stamina Mills, Inc.	Rhode Island	1983
11	West Kingston Town Dump/URI Disposal Area	Rhode Island	1992
12	Western Sand & Gravel	Rhode Island	1983

No.	Site Name	State/Location	Listing Date
1	Aqua-Tech Environmental, Inc. (Groce Labs)	South Carolina	1994
2	Barite Hills Nevada Gold Fields	South Carolina	2009
3	Beaunit Corp. (Circular Knit & Dyeing Plant)	South Carolina	1990
4	Brewer Gold Mine Dam Failure	South Carolina	2005
5	Carolawn, Inc.	South Carolina	1983
6	Elmore Waste Disposal	South Carolina	1989
7	Geiger (C & M Oil)	South Carolina	1984
8	Helena Chemical Co. Landfill	South Carolina	1990
9	Kalama Specialty Chemicals	South Carolina	1984
10	Koppers Co., Inc. (Charleston Plant)	South Carolina	1994
11	Koppers Co., Inc. (Florence Plant)	South Carolina	1984
12	Leonard Chemical Co., Inc.	South Carolina	1984
13	Lexington County Landfill Area	South Carolina	1989
14	Macalloy Corporation	South Carolina	2000
15	Medley Farm Drum Dump	South Carolina	1989
16	Palmetto Wood Preserving	South Carolina	1984
17	Para-Chem Southern, Inc.	South Carolina	1990
18	Parris Island Marine Corps Recruit Depot	South Carolina	1994
19	Rock Hill Chemical Co.	South Carolina	1990
20	Sangamo Weston, Inc./Twelve-Mile Creek/Lake Hartwell PCB Contamination	South Carolina	1990
21	Savannah River Site (U.S. DOE)	South Carolina	1989
22	SCRDI Bluff Road	South Carolina	1983
23	SCRDI Dixiana	South Carolina	1983
24	Shuron, Inc.	South Carolina	1996
25	Townsend Saw Chain Co.	South Carolina	1990
26	Wamchem, Inc.	South Carolina	1984
1	Ellsworth AFB	South Dakota	1990
2	Gilt Edge Mine	South Dakota	2000
1	American Creosote Works, Inc. (Jackson Plant)	Tennessee	1986
2	Arlington Blending & Packaging	Tennessee	1987
3	Carrier Air Conditioning Co.	Tennessee	1990
4	Mallory Capacitor Co.	Tennessee	1989
5	Memphis Defense Depot (DLA)	Tennessee	1992

No.	Site Name	State/Location	Listing Date
6	Milan Army Ammunition Plant	Tennessee	1987
7	Murray-Ohio Dump	Tennessee	1983
8	Oak Ridge Reservation (U.S. DOE)	Tennessee	1989
9	Ross Metals, Inc.	Tennessee	1997
10	Smalley-Piper	Tennessee	2005
11	Tennessee Products	Tennessee	1995
12	Velsicol Chemical Corp. (Hardeman County)	Tennessee	1983
13	Wrigley Charcoal Plant	Tennessee	1989
1	Air Force Plant #4 (General Dynamics)	Texas	1990
2	ALCOA (Point Comfort)/Lavaca Bay	Texas	1994
3	Attebury Grain Storage Facility	Texas	2009
4	Bandera Road Groundwater Plume Site	Texas	2007
5	Brine Service Company	Texas	2002
6	City of Perryton Well No. 2	Texas	1999
7	Conroe Creosoting Co.	Texas	2003
8	Crystal Chemical Co.	Texas	1983
9	Donna Reservoir and Canal System	Texas	2008
10	East 67th Street Groundwater Plume (Devilla)	Texas	2007
11	French, Ltd.	Texas	1983
12	Garland Creosoting	Texas	1999
13	Geneva Industries/Fuhrmann Energy	Texas	1984
14	Gulfco Marine Maintenance	Texas	2003
15	Hart Creosoting Company	Texas	1999
16	Highlands Acid Pit	Texas	1983
17	Jasper Creosoting Company Inc.	Texas	1998
18	Jones Road Groundwater Plume	Texas	2003
19	Koppers Co., Inc. (Texarkana Plant)	Texas	1986
20	Lone Star Army Ammunition Plant	Texas	1987
21	Longhorn Army Ammunition Plant	Texas	1990
22	Malone Service Co.—Swan Lake Plant	Texas	2001
23	Many Diversified Interests, Inc.	Texas	1999
24	Midessa Groundwater Plume	Texas	2008
25	Motco, Inc.	Texas	1983
26	North Cavalcade Street	Texas	1986



No.	Site Name	State/Location	Listing Date
27	Odessa Chromium #1	Texas	1986
28	Old ESCO Manufacturing	Texas	2008
29	Palmer Barge Line	Texas	2000
30	Pantex Plant (U.S. DOE)	Texas	1994
31	Patrick Bayou	Texas	2002
32	Petro-Chemical Systems, Inc. (Turtle Bayou)	Texas	1986
33	Rockwool Industries, Inc.	Texas	1998
34	RSR Corporation	Texas	1995
35	San Jacinto River Waste Pits	Texas	2008
36	Sandy Beach Road Groundwater Plume	Texas	2005
37	Sheridan Disposal Services	Texas	1989
38	Sikes Disposal Pits	Texas	1983
39	Sol Lynn/Industrial Transformers	Texas	1989
40	South Cavalcade Street	Texas	1986
41	Sprague Road Groundwater Plume	Texas	1997
42	Star Lake Canal	Texas	2000
43	State Marine of Port Arthur	Texas	1998
44	State Road 114 Groundwater Plume	Texas	1999
45	Texarkana Wood Preserving Co.	Texas	1986
46	Tex-Tin Corp.	Texas	1990
47	United Creosoting Co.	Texas	1984
48	Van der Horst USA Corp.	Texas	2010
1	Island Chemical Corp/Virgin Islands Chemical Corp.	U.S. Virgin Islands	1996
2	Tutu Wellfield	U.S. Virgin Islands	1995
1	Bountiful/Woods Cross 5th S. PCE Plume	Utah	2001
2	Davenport and Flagstaff Smelters	Utah	2003
3	Eureka Mills	Utah	2002
4	Five Points PCE Plume	Utah	2007
5	Hill Air Force Base	Utah	1987
6	Intermountain Waste Oil Refinery	Utah	2000
7	International Smelting and Refining	Utah	2000
8	Jacobs Smelter	Utah	2000
9	Midvale Slag	Utah	1991
10	Monticello Mill Tailings (U.S. DOE)	Utah	1989

No.	Site Name	State/Location	Listing Date
11	Ogden Defense Depot (DLA)	Utah	1987
12	Portland Cement (Kiln Dust 2 & 3)	Utah	1986
13	Tooele Army Depot (North Area)	Utah	1990
14	U.S. Magnesium	Utah	2009
15	Utah Power & Light/American Barrel Co.	Utah	1989
16	Wasatch Chemical Co. (Lot 6)	Utah	1991
1	Bennington Municipal Sanitary Landfill	Vermont	1989
2	BFI Sanitary Landfill (Rockingham)	Vermont	1989
3	Burgess Brothers Landfill	Vermont	1989
4	Commerce St. Plume	Vermont	2005
5	Elizabeth Mine	Vermont	2001
6	Ely Copper Mine	Vermont	2001
7	Old Springfield Landfill	Vermont	1983
8	Parker Sanitary Landfill	Vermont	1990
9	Pike Hill Copper Mine	Vermont	2004
10	Pine Street Canal	Vermont	1983
11	Pownal Tannery	Vermont	1999
1	Abex Corp.	Virginia	1990
2	Arrowhead Associates, Inc./Scovill Corp.	Virginia	1990
3	Atlantic Wood Industries, Inc.	Virginia	1990
4	Avtex Fibers, Inc.	Virginia	1986
5	Buckingham County Landfill	Virginia	1989
6	Chisman Creek	Virginia	1983
7	C & R Battery Co., Inc.	Virginia	1987
8	Culpeper Wood Preservers, Inc.	Virginia	1989
9	Defense General Supply Center (DLA)	Virginia	1987
10	First Piedmont Corp. Rock Quarry (Route 719)	Virginia	1987
11	Former Nansemond Ordnance Depot	Virginia	1999
12	Fort Eustis (U.S. Army)	Virginia	1994
13	Greenwood Chemical Co.	Virginia	1987
14	H & H Inc., Burn Pit	Virginia	1989
15	Hidden Lane Landfill	Virginia	2008
16	Kim-Stan Landfill	Virginia	1999
17	L. A. Clarke & Son	Virginia	1986

No.	Site Name	State/Location	Listing Date
18	Langley Air Force Base/NASA Langley Research Center	Virginia	1994
19	Marine Corps Combat Development Command	Virginia	1994
20	Naval Amphibious Base Little Creek	Virginia	1999
21	Naval Surface Warfare Center–Dahlgren	Virginia	1992
22	Naval Weapons Station–Yorktown	Virginia	1992
23	Norfolk Naval Base (Sewells Point Naval Complex)	Virginia	1997
24	Norfolk Naval Shipyard	Virginia	1999
25	NWS Yorktown–Cheatham Annex	Virginia	2000
26	Peck Iron and Metal	Virginia	2009
27	Rentokil, Inc. (Virginia Wood Preserving Division)	Virginia	1989
28	Saltville Waste Disposal Ponds	Virginia	1983
29	Saunders Supply Co.	Virginia	1989
30	St. Juliens Creek Annex (U.S. Navy)	Virginia	2000
31	U.S. Titanium	Virginia	1983
1	American Crossarm & Conduit Co.	Washington	1989
2	American Lake Gardens/Mcchord AFB	Washington	1984
3	Bangor Naval Submarine Base	Washington	1990
4	Bangor Ordnance Disposal (U.S. Navy)	Washington	1987
5	Boomsnub/Airco	Washington	1995
6	Centralia Municipal Landfill	Washington	1990
7	Colbert Landfill	Washington	1983
8	Commencement Bay, Near Shore/Tide Flats	Washington	1983
9	Commencement Bay, South Tacoma Channel	Washington	1983
10	Fairchild Air Force Base (4 Waste Areas)	Washington	1989
11	FMC Corp. (Yakima Pit)	Washington	1983
12	Fort Lewis Logistics Center	Washington	1989
13	Frontier Hard Chrome, Inc.	Washington	1983
14	General Electric Co. (Spokane Apparatus Service Shop)	Washington	1989
15	Greenacres Landfill	Washington	1984
16	Hamilton/Labree Roads GW Contamination	Washington	2000
17	Hanford 100-Area (U.S. DOE)	Washington	1989
18	Hanford 200-Area (U.S. DOE)	Washington	1989
19	Hanford 300-Area (U.S. DOE)	Washington	1989
20	Harbor Island (Lead)	Washington	1983
21	Hidden Valley Landfill (Thun Field)	Washington	1989

No.	Site Name	State/Location	Listing Date
22	Jackson Park Housing Complex (U.S. Navy)	Washington	1994
23	Kaiser Aluminum (Mead Works)	Washington	1983
24	Lakewood	Washington	1983
25	Lockheed Shipyard No. 2	Washington	2007
26	Lower Duwamish Waterway	Washington	2001
27	Mica Landfill	Washington	1986
28	Midnite Mine	Washington	2000
29	Midway Landfill	Washington	1986
30	Moses Lake Wellfield Contamination	Washington	1992
31	Naval Air Station, Whidbey Island (Ault Field)	Washington	1990
32	Naval Undersea Warfare Engineering Station (4 Waste Areas)	Washington	1989
33	North Market Street	Washington	1990
34	Northside Landfill	Washington	1986
35	Oeser Co.	Washington	1997
36	Old Navy Dump/Manchester Laboratory (U.S. EPA/NOAA)	Washington	1994
37	Pacific Car & Foundry Co.	Washington	1990
38	Pacific Sound Resources	Washington	1994
39	Palermo Well Field Groundwater Contamination	Washington	1997
40	Pasco Sanitary Landfill	Washington	1990
41	Puget Sound Naval Shipyard Complex	Washington	1994
42	Queen City Farms	Washington	1984
43	Quendall Terminals	Washington	2006
44	Seattle Municipal Landfill (Kent Highlands)	Washington	1990
45	Vancouver Water Station #1 Contamination	Washington	1994
46	Vancouver Water Station #4 Contamination	Washington	1992
47	Western Processing Co., Inc.	Washington	1983
48	Wyckoff Co./Eagle Harbor	Washington	1987
1	Allegany Ballistics Laboratory (U.S. Navy)	West Virginia	1994
2	Big John Salvage—Hoult Road	West Virginia	2000
3	Fike Chemical, Inc.	West Virginia	1983
4	Hanlin-Allied-Olin	West Virginia	1999
5	Ordnance Works Disposal Areas	West Virginia	1986
6	Ravenswood PCE	West Virginia	2004
7	Sharon Steel Corp. (Fairmont Coke Works)	West Virginia	1996
8	Vienna Tetrachloroethene	West Virginia	1999



No.	Site Name	State/Location	Listing Date
9	West Virginia Ordnance (U.S. Army)	West Virginia	1983
1	Algoma Municipal Landfill	Wisconsin	1987
2	Ashland/Northern States Power Lakefront	Wisconsin	2002
3	Better Brite Plating Co. Chrome and Zinc Shops	Wisconsin	1990
4	City Disposal Corp. Landfill	Wisconsin	1984
5	Delavan Municipal Well #4	Wisconsin	1984
6	Eau Claire Municipal Well Field	Wisconsin	1984
7	Hagen Farm	Wisconsin	1987
8	Hechimovich Sanitary Landfill	Wisconsin	1989
9	Hunts Disposal Landfill	Wisconsin	1987
10	Janesville Ash Beds	Wisconsin	1984
11	Janesville Old Landfill	Wisconsin	1984
12	Kohler Co. Landfill	Wisconsin	1984
13	Lauer I Sanitary Landfill	Wisconsin	1984
14	Lemberger Landfill, Inc.	Wisconsin	1986
15	Lemberger Transport & Recycling	Wisconsin	1984
16	Madison Metropolitan Sewerage District Lagoons	Wisconsin	1990
17	Master Disposal Service Landfill	Wisconsin	1984
18	Mid-State Disposal, Inc. Landfill	Wisconsin	1984
19	Moss-American Co., Inc. (Kerr-McGee Oil Co.)	Wisconsin	1984
20	Muskego Sanitary Landfill	Wisconsin	1984
21	N. W. Mauthe Co., Inc.	Wisconsin	1989
22	National Presto Industries, Inc.	Wisconsin	1986
23	Oconomowoc Electroplating Co., Inc.	Wisconsin	1984
24	Onalaska Municipal Landfill	Wisconsin	1984
25	Penta Wood Products	Wisconsin	1996
26	Refuse Hideaway Landfill	Wisconsin	1992
27	Ripon City Landfill	Wisconsin	1994
28	Sauk County Landfill	Wisconsin	1989
29	Schmalz Dump	Wisconsin	1984
30	Scrap Processing Co., Inc.	Wisconsin	1984
31	Sheboygan Harbor & River	Wisconsin	1986
32	Spickler Landfill	Wisconsin	1987
33	Stoughton City Landfill	Wisconsin	1986
34	Tomah Armory	Wisconsin	1987

No.	Site Name	State/Location	Listing Date
35	Tomah Municipal Sanitary Landfill	Wisconsin	1989
36	Waste Management of Wisconsin, Inc. (Brookfield Sanitary Landfill)	Wisconsin	1990
37	Wausau Groundwater Contamination	Wisconsin	1986
1	F. E. Warren Air Force Base	Wyoming	1990
2	Mystery Bridge Rd./U.S. Highway 20	Wyoming	1990

# APPENDIX XIII

## TOP 25 OIL SPILLS IN THE WORLD

Rank	Date	Incident/Location	Millions of Gallons (Liters)
1	January 26, 1991	Terminals, tankers, eight sources total Sea Island installations; Kuwait; Persian Gulf; Saudi Arabia	240.0 (90 7.2)
2	April 20, 2010	Exploratory well <i>Deepwater Horizon</i> ; 40 miles (66 km) off the SE coast of Louisiana, United States; Gulf of Mexico	204 (775.2)
3	June 3, 1979	Exploratory well Ixtoc I; Mexico; Gulf of Mexico, Bahía de Campeche; 48 miles (80 km) NW of Ciudad del Carmen, Campeche	140.0 (529.2)
4	February 4, 1983	Platform #3 well (Nowruz) Iran; Persian Gulf, Nowruz Field	80.0 (302.4)
5	August 6, 1983	Tanker <i>Castillo de Bellver</i> ; South Africa; Atlantic Ocean, 38.4 miles (64 km) off Table Bay	78.5 (296.7)
6	March 16, 1978	Tanker <i>Amoco Cadiz</i> ; France; Atlantic Ocean, off Porsall, Brittany	68.7 (259.7)
7	November 10, 1988	Tanker <i>Odyssey</i> ; Canada; North Atlantic Ocean, 705 miles (1,175 km) NE of St. John's, Newfoundland	43.1 (162.9)
8	July 19, 1979	Tanker <i>Atlantic Empress</i> ; Trinidad and Tobago; Caribbean Sea, 19.2 miles (32 km) NE of Trinidad-and Tobago	42.7* (161.4)
9	April 11, 1991	Tanker <i>Haven</i> ; Italy; Mediterranean Sea, port of Genoa	42.0 (158.8)
10	August 2, 1979	Tanker <i>Atlantic Empress</i> ; 370 miles (450 km) east of Barbados	41.5* (156.9)
11	March 18, 1967	Tanker <i>Torrey Canyon</i> ; United Kingdom; Lands End	38.2 (144.4)
12	December 19, 1972	Tanker <i>Sea Star</i> ; Oman; Gulf of Oman	37.9 (143.3)
13	February 23, 1980	Tanker <i>Irenes Serenade</i> ; Greece; Mediterranean Sea, Navarino Bay	36.6 (138.3)
14	December 7, 1971	Tanker <i>Texaco Denmark</i> ; Belgium; North Sea	31.5 (119.1)
15	February 23, 1980	Tanker <i>Hawaiian Patriot</i> ; United States; Pacific Ocean, 356 miles (593 km) west of Kauai Island, Hawaii	31.2** (117.9)
16	November 15, 1979	Tanker <i>Independenza</i> ; Turkey, Bosphorus Strait near Istanbul	28.9 (109.2)

Rank	Date	Incident/Location	Millions of Gallons (Liters)
17	February 11, 1969	Tanker <i>Julius Schindler</i> ; Portugal; Ponta Delgada, Azores Islands	28.4 (107.3)
18	May 12, 1976	Tanker <i>Urquiola</i> ; Spain; La Coruña Harbor port	28.1 (106.2)
19	January 5, 1993	Tanker <i>Braer</i> ; United Kingdom; Garth Ness, Shetland Islands	25.0 (94.5)
20	January 29, 1975	Tanker <i>Jacob Maersk</i> ; Portugal; Porto de Leixões, Oporto	24.3 (91.8)
21	December 3, 1992	Double-bottom tanker <i>Aegean Sea</i> ; Spain; La Coruña Harbor port	21.9 (82.8)
22	December 6, 1985	Tanker <i>Nova</i> ; Iran; Persian Gulf, 84 miles (140 km) south of Kharg Island	21.4 (80.9)
23	February 15, 1996	Tanker <i>Sea Empress</i> ; United Kingdom; Mill Bay near entrance to Milford Haven Harbor port	21.3 (80.5)
24	February 27, 1971	Tanker <i>Wafra</i> ; South Africa; Atlantic Ocean	20.2 (76.4)
25	December 19, 1989	Tanker <i>Khark 5</i> ; Morocco; Atlantic Ocean, 111 miles (185 km) from Moroccan coast	20.0 (75.6)

## Notes:

\* On July 19, 1979, the *Atlantic Empress* spilled 42.7 million gallons (162.3 million L) of oil as the result of a collision with the *Aegean Captain* in the Caribbean Sea near Trinidad and Tobago. In this incident, the *Aegean Captain* spilled 4.31 million gallons (16.4 million L) of oil. On August 2, 1979, while under tow from the original spill site, the *Atlantic Empress* spilled an additional 41.5 million gallons (157.7 million L).

\*\* In this incident the vessel sank with some of its cargo still onboard after spilling an undetermined amount of oil. The spill size reported reflects the total amount of oil spilled and oil left onboard the sinking vessel. Estimates of the two accounts are not available.

Misc: There have been 55 marine oil spills exceeding 10 million gallons (33 million L) since 1960.

Source: Data from *Oil Spill Intelligence Report*, Arlington, Mass. Web site: <http://cutter.com/osir/biglist.htm>.



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